THE STRATIGRAPHICAL OCCURRENCE AND PALAEOECOLOGY OF SOME AUSTRALIAN TERTIARY MARSUPIALS.

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ABSTRACT.

A. *Wynyardia bassiana* is a Lower Tertiary possum from Northern Tasmania whose provenance has been checked by the fluorine test and other investigations. It was apparently swept down a river and entombed as a carcase in marine calcareous mud because the bones were largely in their correct relative positions.

B. In the Hamilton district of Victoria, part of the ramus of a kangaroo in a Lower Pliocene marine bed suggests some kind of grassland environment, and indicates an older origin for the kangaroos than some have previously accepted. In a swampland environment with a conifer-eucalypt forest rich in ferns, and with ponds rich in diatoms and sponges, there lived a cuscus represented by a fossil molar. Volcanic ash fell on this landscape which was subsequently obliterated by lava flows. The climate was pluvial and warmer than the present. There is evidence to suggest that the Grampian Mountains were uplifted at this time.

C. The recognition of marine and non-marine members of the Sandringham Sands formation in the Port Phillip area, the dating of the latter member by pollen analysis, and the consideration of the varying facies involved, assist in understanding the Upper Miocene marine beds at Beaumaris whence came a number of marsupial bones. Fluorine tests have checked their provenance.

D.-E. The Tertiary marsupial fauna of Australia as at present known is listed, and a number of localities of possible Tertiary age which have yielded marsupial fossils is discussed.

CONTENTS.

Introduction.

In the year 1900, Professor Baldwin Spencer published his monograph on *Wynyardia bassiana* and thus the nature of Australia's first Tertiary marsupial became known. With the help of fluorine tests, a number of others has recently been recognized, and this paper is written to elucidate their stratigraphical occurrence. Most of these marsupials occur in shallow water marine deposits and the marine fossils thus date them with some precision.

A. Occurrence of *Wynyardia* at Wynyard, Tasmania.

1. Stratigraphy.—The possum *Wynyardia bassiana* was found in the Janjukian limestone at the cliff called Fossil Bluff which faces Bass Strait at the eastern edge of the delta of the Inglis River in Northern Tasmania (see text-fig. 1). The locality is on the outskirts of the township of Wynyard, but is often referred to in the literature as Table Cape, a prominent basaltic headland a little further west. It is more accurate to refer to the site as Fossil Bluff, Wynyard. The site and its fossils have been described by Johnston (1876, 1887, 1880A, 1885A, B, C, 1888), Tenison Woods 1876A, B, C, 1877), Stephens (1870), Scott (1914), Scott and Lord (1922), Flynn (1932), Tate (1885A, B), May (1919A, B, 1922), Pritchard (1896, 1913), Chapman (1922), Chapman and Crespin (1923, 1935), Duncan (1875, 1876), Ashby (1925), and others. The writer (Gill, 1955) has commented on the palaeoecology of the beds. The site has been proclaimed a reserved area for scientific purposes (Anonymous, 1920).

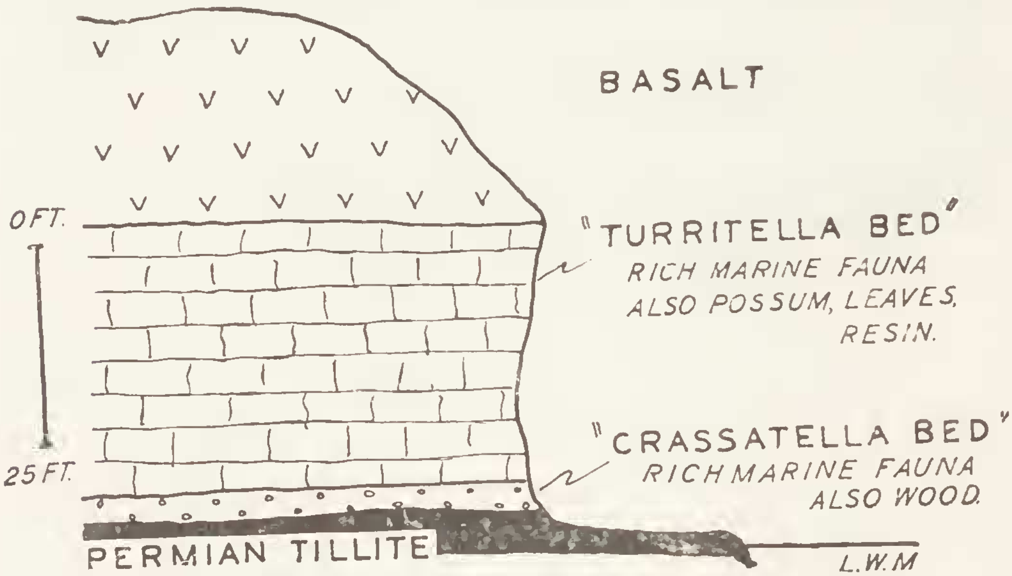
The first reference in literature to *Wynyardia* appears to be that of Tenison Woods (1876, p. 28), who after describing *Turritella sturtii* stated, " In the Museum there is a large block of yellow calcareous sandstone from Table Cape, principally composed of this fossil, with an almost complete skeleton of a small marsupial herbivore imbedded. (*Macropus* or *Halmaturus?*)." Johnston (1888) mentioned it, and later Tate (1894) gave the following account:—

" The skeleton of a marsupial is recorded by Mr. R. M. Johnston from the 'Turritella beds' at Table Cape, and by him referred to the living genus *Halmaturus* without specific name. At the time of writing my Census, I had thought it possible that the specimen might be of recent date, and had reached its position by way of a vertical fissure from the surface, and it was accordingly omitted. During the meeting of the Australasian Association for the Advancement of Science at Hobart, the slab containing the skeleton was carefully examined by Professors Hutton and Spencer and myself, and by us was unhesitatingly pronounced to be lying in the bedding plane of the rock. Subsequently Professor Spencer and myself visited Table Cape to study its stratigraphical features, with the result that this extensive vertical section represents one period of deposition, gradually passing from the basal conglomerates and coarse grits, rich in marine fossils, to the 'Turritella beds', in which the species have been greatly reduced in number, and to estuarine or fluviatile beds with plant-remains only. This discovery is of the highest interest, as hitherto no marsupial remains are known older that the age of *Diprotodon* or Pliocene; and leads us to hope that other progenitors of the modern Marsupialia of this Continent may yet be found, and so help to solve the question of their geographic origin. Professor Spencer has promised to investigate the fossil with the view to determine the classificatory position of the oldest known Australian marsupial."

TEXT-FIGURE 1.—Locality map of South-East Australia.

Spencer (1900) kept his promise. One of his original drawings is reproduced in Plate 1. In 1930, Wood Jones redescribed and reinterpreted this important fossil. The references in literature to *Wynyardia* are legion, and for the present purpose it may be enough to mention the discussions by Abbie (1941), Anderson (1925, 1936, 1940), Longman (1924), Pearson (1947), and Simpson (1930). After Tate expressed his hope of further finds of Tertiary marsupials in Australia, 59 years passed before further definite records were established (Gill, 1953A, B).

The stratigraphical succession at Fossil Bluff is as shown in text-fig. 2, and the actual cliff is illustrated in Plate 2, figs. 1-2. The Tertiary sediments rest on a Permian tillite (Kitson, 1902:



TEXT-FIGURE 2.—Geological Section of Fossil Bluff, near Wynyard, northern Tasmania. *Wynyardia* came from the "*Turritella Bed.*"

David, 1907; Noetling, 1909) with large drop pebbles. This tillite forms the shore platform at Fossil Bluff. Over the tillite lies the "*Crassatella* bed" without any intervening fossil soil or other evidence of subaerial weathering. The bed is about 3 feet thick at Fossil Bluff, and consists of a conglomerate containing numerous pebbles of different kinds such as can be found in the tillite underneath. In addition there is gravel, sand, and finer fractions. There is a large calcareous fraction consisting of the skeletons (mostly broken) of marine organisms (mollusca predominating). The sediments are very poorly sorted. The lithology of the beds as such has not been studied, but the above description is enough to indicate a shallow water, near-shore environment with strong currents. The large heavy-shelled *Crassatella* was particularly successful in this habitat. Johnston (1876) reported fossil wood from this bed.

Without any apparent stratigraphic break, the " *Crassatella* bed " is succeeded by the " *Turritella* bed ". M. R. Banks of the University of Tasmania and the writer visited the site and 1952 and agreed that there is no disconformity or diastem in the succession. The " *Turritella* bed " is a fine-grained clayey limestone, and the lower part of it is particularly rich in fossils. From this bed came *Wynyardia*. Of ecological interest is the fact that fossil leaves (Johnston, 1887, p. xx., plates A, B following p. 248; 1888, pp. 182, 185) and a waterworn pebble of resin (Gill, 1955) have come from this bed.

2. *Age.*—In the past 75 years many different ages have been attributed to the Tertiary beds at Fossil Bluff. Some of these differences are due to the fact that certain determinations antedate the acceptance of the Oligocene Period. Others are due to different ideas as to their antiqnity. However, for some time it has been agreed that they are of Janjukian age. Raggatt and Crespin (1952) claim this stage to be of Eocene age, whereas Singleton (1941) and Glaessner (1953) regard it as Oligocene. Even at the latter younger age, *Wynyardia* is still Australia's earliest known marsupial.

3. *The Fossil.*—When visiting Hobart in 1954, the writer examined the bones of *Wynyardia bassiana* at the Tasmanian Museum, this being made possible by the kind co-operation of the Director, Dr. W. Bryden, and the Honorary Palaeontologist, M. R. Banks. The original position of the bones in the *Turritella* limestone can be seen in Plate 50A of David and Browne (1950). Most of the bones were freed from the matrix for the original study of *Wynyardia*, and the remaining ones have now been extracted by Mr. Banks. The bones were so solidly embedded that they gave no hint of being anything but *in situ*. The following list of skeletal remains was made:—

Imperfect cranium.
Ramus of mandible (no teeth; pathological malformation).
Two pieces of the pelvic girdle.
Six imperfect long bones or pieces thereof.
Thirteen vertebrae or pieces thereof.
Ten ribs or pieces thereof.
Thirty-three small fragments.

This makes a total of 66 pieces of skeleton. In the National Museum of Victoria is a rib collected by F. A. Cudmore many years ago from the same bed at the same site which could be part of the same skeleton. It was collected *in situ* from the "upper bed", and so if established will constitute evidence to be taken with other facts to indicate that the skeleton of *Wynyardia* was really in place in the cliff.

4. *Ecological Observations.*—*Wynyardia bassiana* is a land animal found in a marine bed, and the examination of the bones preserved throws some light on how it came to be where it was found.

(*a*) No bone shows any appreciable wear. The neural spines and transverse processes of the vertebrae, although so strongly projecting, and in certain cases quite thin, show no sign of abrasion as distinct from fracture or solution.

(*b*) The bones are of such dissimilar sizes, shapes, and weights that if they were merely sedimentary materials, they could only appear in quite unsorted sediments, whereas in fact they occur in well-sorted sediments. The size and weight of the bones make them quite out of character with the fine sediments in which they were found and so cannot be considered as moved into place by water movements and deposited as sediments.

(*c*) A cast of *Wynyardia* in its original position in the matrix as well as the photo referred to above, show that the bones were not lying haphazard on the sea-floor, but were to a certain extent in their positions of articulation. The vertebral column was largely in place, the cranium was at one end of the column, and the pelvic bones with some leg bones at the other. The bones obviously arrived together and not in a disarticulated condition. *Wynyardia* must therefore have floated as a carcase to more or less the position where it was found. It would be brought by the flow of a river and probably also marine currents. The wind could affect a floating object such as this. The presence of leaves, wood, and resin in these beds, as well as the possum, suggest that a river debouched nearby. If this skeleton had floated into this area when the *Crassatella* bed was being laid down, it would surely have been destroyed in the rather turbulent waters. It would certainly have been scattered. In the quiet waters of the *Turritella* bed environment, the carcase sank to the sea floor, and bones lay little disturbed until covered by sediment (*cf.* Wintle, 1886, p. 45).

(*d*) An examination of the cast of *Wynyardia in situ* shows that the dorsal surface of the cranium was buried in the limestone, with the result that the palate was exposed to the attack of the sea when the block in which it was held fell to the shore platform at Fossil Bluff (see Pl. 2, figs. 1-3). It is probable that there were teeth present when the fossil was first exposed to marine attack, but that they were knocked out and the palate eroded. Since *Wynyardia* arrived as a complete carcase, it would be very strange if it had no teeth. Likewise the ramus was in such a position that the sea could remove any teeth that were present. There is no reason for considering that the animal may have been edentulous because no teeth are preserved. In any case "the broken alveolar cavity for the roots of the third molar is clearly retained" (Wood Jones, 1930, p. 108).

(*e*) The mandibular ramus of *Wynyardia bassiana* has a curious structure in the region of the second molar tooth which Wood Jones has interpreted as a pathological one, the most probable diagnosis being an alveolar abscess cavity. In spite of this the animal reached maturity, but there is no doubt that the disability (however the malformation be interpreted) would affect its nutrition. It was probably swept out to sea where it found its way into quiet waters away from the turbulence of the open sea. It sank to the bottom, settling into a soft limey mud where a colony of gasteropods (*Turritella*) thrived, and in time was naturally interred. The marine muds preserved the bones for some 40 or 50 million years until marine erosion at Fossil Bluff at the end of the nineteenth century A.D. brought this interesting fossil to light.

(*f*) Many Tertiary limestones in S.-E. Australia have a vertical cleavage so that large pieces flake off coastal cliffs formed of these rocks. Such a block, containing the bones of *Wynyardia*, fell from the sea cliff at Fossil Bluff on to the hard shore platform of Permian tillite (Plate 2, fig. 3). The sea beats directly against the cliff, and so the block was immediately attacked by the sea. *Wynyardia* was thus found *in situ* in the *Turritella* limestone, but not *in situ* in the cliff. On account of the uncertainties that can attend any such occurrence, and because of the close similarity between *Wynyardia* and living possums, some workers doubted whether *Wynyardia* was as old as the rock in which it was found. One suggestion was that a possum may have fallen down a crevice where its bones were covered with rock waste from the limestone which became cemented by solutions of calcium carbonate. To determine whether *Wynyardia* was in fact as old as the *Turritella* limestone, the fluorine test was applied (Gill (1954D). Mr. W. R. Jewell, Chief Government Chemist, and his staff at the State

Laboratories, Melbourne, kindly carried out the fluorine and phosphate analyses with the following results:—

Specimen.	Percentage F.	Percentage P_2O_5.	Fluorine Index.*
1. *Wynyardia bassiana* Spencer 1900. Portion of a rib	3·10	30·0	10·3
2. Ditto	3·05	31·6	9·7
3. Ditto	3·05	31·2	9·8
4. *Wynyardia bassiana.* Portion of a vertebra	3·05	30·9	9·9
5. Fragments of whale bone	2·85	29·9	9·5
6. Tooth of Hybodontoid shark *Strophodus* (= *Asteracanthus*) *eocenicus* Tate 1894 from "*Turritella* bed"	2·80	33·1	8·5
7. Ditto. Tooth from the "Crassatella bed"	2·85	34·0	8·4
8. Fish vertebra (somewhat silicified) from the "Turritella bed"	2·10	25·5	8·2

* The fluorine index is $\frac{\%F \times 100}{\%P_2O_5}$.

The fluorine percentages are rounded off to the nearest 0·05 as the figures are considered significant to this amount. The first five specimens in the above list of analyses were kindly provided by the Tasmanian Museum, while the remainder came from the National Museum of Victoria (F. A. Cudmore Collection). Typical *Turritella* bed matrix was removed from specimen 6, and this has been preserved.

The results of the fluorine test may be summarized thus:—

Wynyardia bassiana ..	Fluorine	index	9·9 (average)
Whale bone	,,	,,	9·5
Shark's tooth (upper bed)	,,	,,	8·5
Shark's tooth (lower bed)	,,	,,	8·4
Silicified fish vertebra ..	,,	,,	8·2

The *Wynyardia* and whale indices, both established on skeletal bones (see Gill, 1955, concerning the importance of this), are closely comparable. The teeth, being less permeable, have a lower index, as is to be expected. The small difference between the index of a tooth from the lower bed, and that of a tooth of the same species from the upper bed, may be taken as additional evidence that there is no stratigraphical break in the Fossil Bluff strata. They belong to the one cycle of sedimentation. The lower index of the fish vertebra is understandable in view of its silicification. This mineralization may have its origin in solutions from the decomposing basalt above.

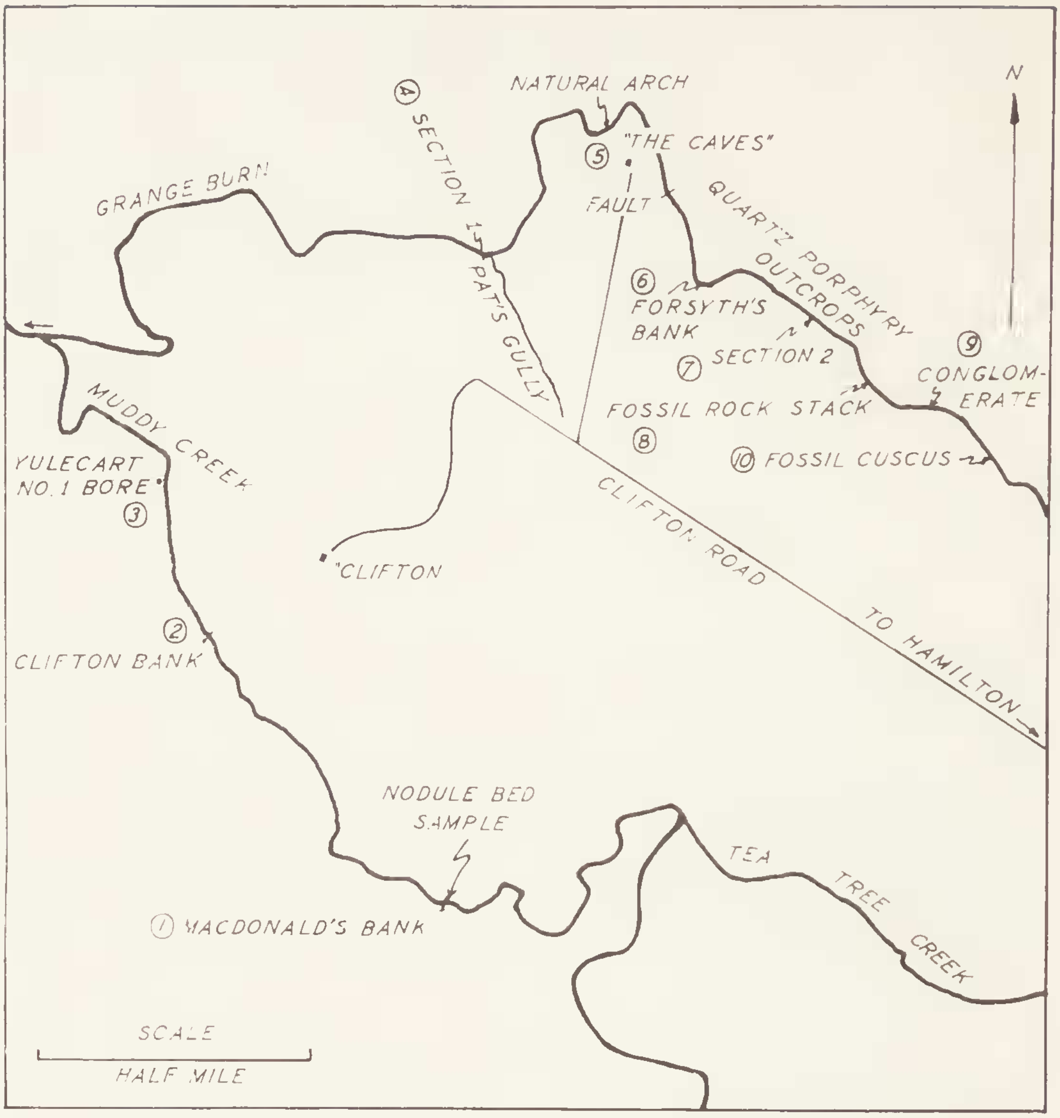
Wynyardia is a *Trichosurus* type possum, and a control for the fluorine test is provided by the analysis of a piece of the anterior end of the mandible of a present-day *Trichosurus vulpecula* from Wynyard. The contrasting figures are as follows:—

Animal.	% F.	% P_2O_5.	Fluorine Index.
1. *Wynyardia bassiana* (Tertiary). Average	3·06	30·9	9·9
2. *Trichosurus vulpecula* (Extant) ..	0·005	25·1	0·02

Wynyardia therefore has a fluorine index nearly 500 times as great as that of a possum living in the same area in modern times. Fossil bones with fluorine indices comparable with that of *Wynyardia* are found in the Tertiary beds of the Beaumaris and Hamilton districts of Victoria (Gill, 1953A, B, 1955). Thus the fluorine test, with the other evidence outlined earlier in this paper, proves that *Wynyardia* is a valid fossil having the same age as the *Turritella* bed in which it was found.

B. Occurrence of Tertiary Marsupials at Hamilton, Victoria.

1. *Grange Burn.*—The geology of the Hamilton area was first described nearly 100 years ago by Bonwick (1858), but he made no mention of the Tertiary fossiliferous beds, so probably they had not been discovered then. Descriptions of Tertiary fossils from the Hamilton district appeared in the 1860's, and the localities on Muddy Creek, Violet Creek, and Grange Burn have become classic for Tertiary studies in Victoria. The references in literature are far too numerous to warrant being listed here, but the principal discoveries are recorded in Ashby and Cotton (1939), Chapman (1914, 1916, 1923), Chapman and Cudmore (1924, 1934), Colliver (1933), Crespin (1936), David and Browne (1950), Dennant (1889), Duncan (1865, 1875, 1876), Gill (1952, 1953A, B), Howchin (1889, 1890, 1891), Parr (1926, 1939), Withers (1953).



TEXT-FIGURE 3. Locality map of the area west of Hamilton, Victoria. Numbers in circles are localities so numbered in the text. Locality 11 (diatomite and polleniferous clay) is on Grange Burn 1¼ mile east of the edge of the map.

In Victoria there are three Tertiary sedimentary basins of different sizes, viz., the Portland-Mt. Gambier 2-lobed sunkland in the west, the Port Phillip sunkland in the central area, and the Gippsland sunkland in the east. Peripheral to these basins are thin shelf deposits. Most of the type sections for the various Tertiary stages established in Victoria are in the thin shelf deposits. There have not been the orogenic movements to cause exposure of great thicknesses of Tertiary rocks such as can be seen in New Zealand. The Tertiary beds at Hamilton are thin shelf deposits. Boutakoff and Sprigg (1953) have listed two formations which they name "Muddy Creek" (Miocene) and "Grange Burn" (Lower Pliocene). As a number of observers have noted in the past (e.g. Chapman, 1914), there are actually three formations in this area, viz.:—

Youngest Grange Burn Coquina.
Muddy Creek Marl.
Oldest Bochara Limestone (here named after the Parish of Bochara).

Boutakoff and Sprigg merge the two older formations, but the writer finds that these three lithological units can be mapped in the field with facility, and so prefers the traditional division into three formations. Singleton (1941) outlines the history of the controversy concerning the order of succession of these three formations, a question settled ultimately by the Yulecart No. 1 bore. However, the writer has found that the three formations outcrop in one section (marked section 1 in text-fig. 3) on the south bank of Grange Burn at Pat's Gully (see text-fig. 4). Auger holes were put down to remove any possible doubt concerning the relationships of the highest formation, which is largely covered with soil and grass, although the typical fossils are abundant therein. Auger Hole 1 on the section line 3 feet north of the fence penetrated:—

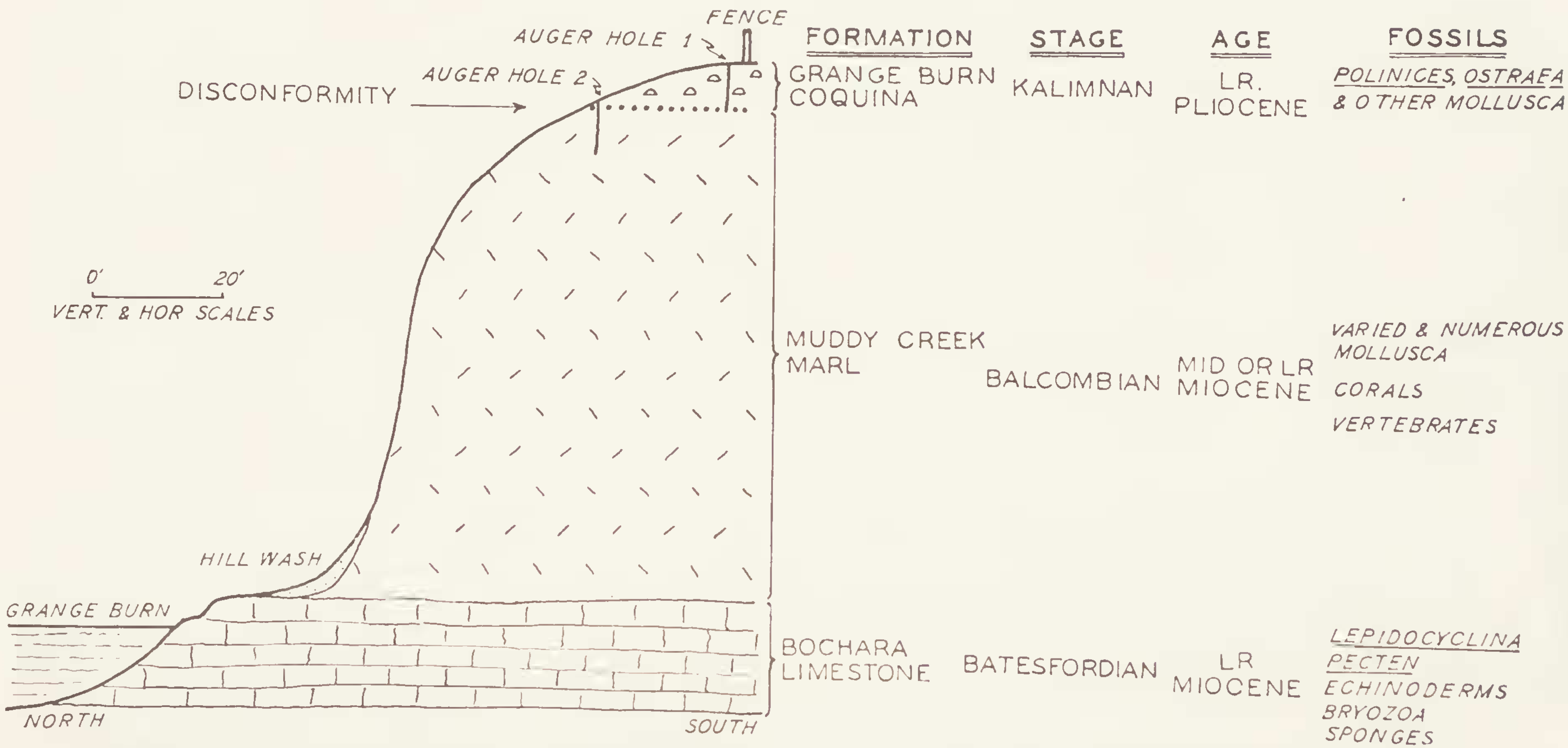
0 in. to 9 ins.—Dark chocolate soil with basalt boulders and small limestone nodules.

9 ins. to 6 ft. 9 ins.—Fawn earthy limestone or calcareous sand. At 1 ft. 3 ins. band of *Polinices* in hard crystalline limestone. Limey at 32 ins. (Pedological effect), and at 3 ft. 3 ins. a thin hard band below which were numerous limestone nodules. Fossils, including *Polinices*. At 5 ft. 6 ins. to 5 ft. 9 ins. large subspherical limestone nodules of varying sizes but commonly 4 to 5 cm. in diameter and consisting of fine well-rounded quartz sand with some mica, lithified by a calcareous cement. Another *Polinices* horizon at 5 ft. 10 ins. Numerous nodules of different kinds at junction with underlying marl bed.

6 ft. 9 ins.—Grey clayey marl (Balcombian).

Auger Hole 2 on the section line 23 feet north of fence penetrated:—

0 in. to 10 ins.—Dark chocolate soil with pieces of limestone, nodules, and shells of *Polinices, Ostrea, &c.* (Kalimnan). The nodules are like those at 5 ft. 6 ins.



TEXT-FIGURE 4.—Section on south bank of Grange Burn at Pat's Gully (loc. 4 on map) showing succession of Tertiary formations. Here proposed as type section for the three formations appearing therein.

to 5 ft. 9 ins. in Auger Hole 1 but smaller. On digestion in acid there was a similar residue of fine well-rounded quartz and some mica, but there was also an appreciable amount of carbonaceous matter.

10 ins. to 6 ft. 8 ins.—Fawn earthy clayey limestone. Free lime at 32 ins. a little more clayey at 3 ft. 3 ins., firmer and greyer (especially inside lumps) at 4 ft. 2 ins., *Corbula* at 4 ft. 6 ins. and further fossils at 5 ft. 6 ins., iron enrichment at 5 ft. 8 ins., and typical Balcombian marl at 6 ft. 8 ins.

6 ft. 8 ins. to 7 ft. 8 ins.—Marl.

This auger hole log may be summarized thus:—

0 in. to 10 ins.—Soil and Kalimnan fossils.

10 ins. to 6 ft. 8 ins.—Weathered Balcombian marl.

6 ft. 8 ins. to 7 ft. 8 ins.—Fresh (although still somewhat oxidized) Balcombian marl.

In the section at Pat's Gully the outcrops of the three formations are rich in fossils.

As far as outcrops indicate, the basement rock in this area is quartz porphyry (see text-fig. 3). No laboratory determinations of the rocks have been made, the names given being field ones only. The Bochara Limestone (lowest of the three Tertiary formations) is highly calcareous and is lithified so as to be crystalline in part. The strata are horizontal or with low dips. They constitute the creek cliff at Henty's (loc. 5) where they have a slight westerly dip. A short distance east of Henty's they abut against the Muddy Creek Marl, the junction consisting of a reversed fault (see text-figure 3) with a throw of the order of 100 feet. This is the largest fault noted in the area studied. The marl appears to have been pulled up a little by the fault so that it has a slight easterly dip. Near the end of Clifton-road, cliffs expose about 50 feet of Bochara Limestone, but that the formation is thicker than this is proved by the Yulecart No. 1 bore (Mines Dept., 1938). The fossils indicate a marine environment of warm clear water.

The boundary between the Bochara Limestone and the overlying Muddy Creek Marl is a sharp and conformable one. Many springs emerge along this contact. The Bochara Limestone can be followed on Grange Burn in its more or less westerly dip from Henty's, and as the Muddy Creek Marl appears in the creek walls, the vertical cliffs caused by the Bochara Limestone give way to the sloping banks caused by the marl. This difference in lithology is the origin of the terraces downstream from Henty's which Chapman (1914, fig. 16) interpreted as due to a rejuvenation of the stream. This formation is unlithified and so the name " marl " rather than " marlstone " is applied to it. The formation is very consistent in character throughout the outcrops of the area. Quiet waters of moderate depth are indicated. There is a remarkably rich fauna containing over 400 species of described mollusca alone. Lepidocyclines still occur but not in the rock-forming quantities found in the Bochara Limestone. There is evidence of decreasing temperature through the three formations from below up, but the climate at the end of that period of time was still warmer than the present. This decrease in temperature through the Miocene and Pliocene was apparently worldwide, and recently Emiliani (1954) has traced it by the oxygen isotope method of palaeotemperature measurement.

Disconformity.—Of stratigraphical importance is the disconformity between the Muddy Creek Marl and the Grange Burn Coquina, marked by a nodule bed. There is room for difference of opinion on what to call the Grange Burn formation. On Muddy Creek it consists of a shell bed only, while on Grange Burn the same shell bed occurs but over it is a sandy limestone which is generally highly fossiliferous too. The shells are both whole and broken. The term " Coquina " as used by Rodgers (1954) appears to the writer to be the best term to use.

For the study of this disconformity, a site was selected at MacDonald's Bank on Muddy Creek where the nodule bed is clearly developed, and a portion of it 24 ins. long, by 4 ins. wide, by 2 ins. thick vertically was excavated. Every nodule 5 mm. or more in diameter was collected. A total of 208 nodules was obtained including a large piece of whalebone which overlapped the boundaries of the area given. The nodules comprised:—

1 subrectangular piece of dark-brown mineralized whalebone with rounded edges and a bright surface glaze. It measures 20 cm. by 5 cm. by 2 cm. approximately.

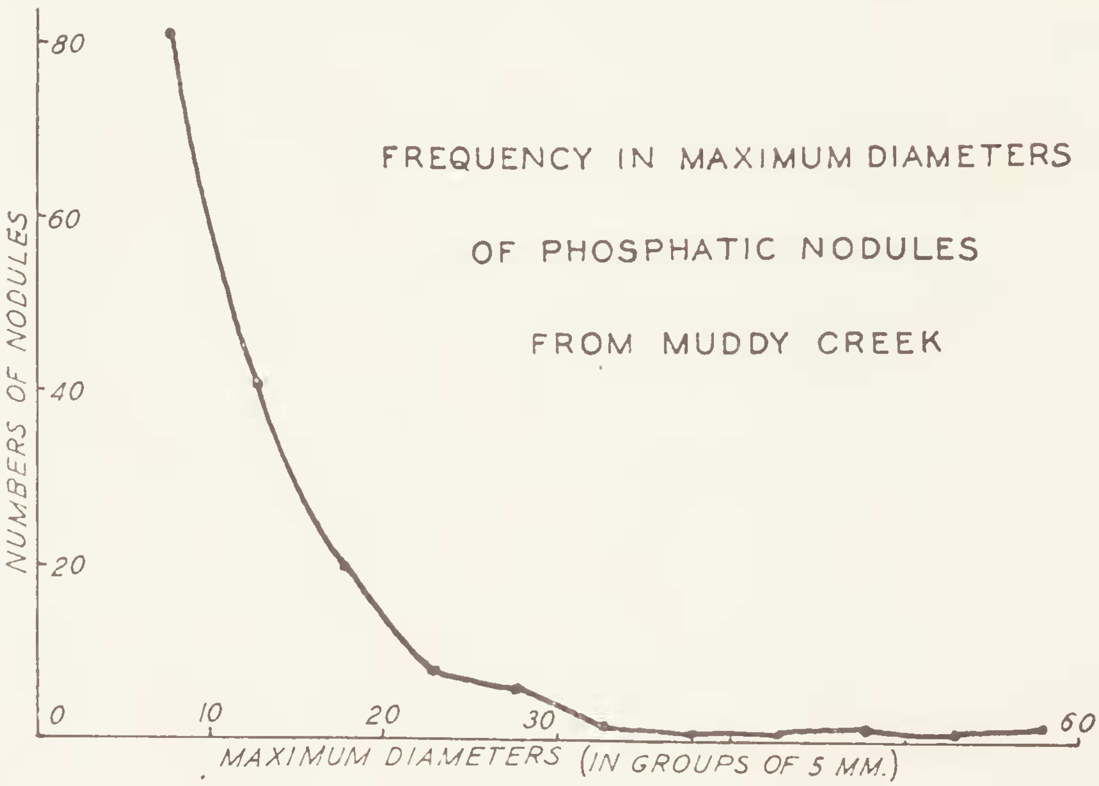
41 waterworn fossil fragments—pieces of mollusc shells, cidaroid spines, bryozoa and bone varying in size and in degree of mineralization. One shell fragment 19 mm. by 14 mm. by 8 mm. consists of the umbonal portion of a heavy lamellibranch shell and is much bored by marine molluscs.

166 phosphatic nodules consisting chiefly of pieces of fossiliferous marlstone indurated in varying degrees with phosphate and iron oxide; some contain glauconite. Mr. G. Baker kindly demonstrated the phosphatic nature of these nodules. All are well rounded, and most of them possess a moderate sphericity, but some are flattish and some sub-cylindrical. Some have encrusting bryozoa and some show evidence of boring. A few nodules have been broken and then rounded on the edges and glazed. One contains a nodule formed at an earlier time. The glaze or polish on the nodules does not penetrate steep-sided depressions and so has apparently been induced by surface friction and is not a chemical precipitate, or not entirely so. A size analysis based on maximum diameters showed the following distribution of sizes among the 166 phosphatic nodules:—

5 mm. to 9 mm.	inclusive ..	81	nodules
10 mm. to 14 mm.	,, ..	41	,,
15 mm. to 19 mm.	,, ..	20	,,
20 mm. to 24 mm.	,, ..	8	,,
25 mm. to 29 mm.	,, ..	6	,,
30 mm. to 34 mm.	,, ..	2	,,
35 mm. to 39 mm.	,, ..	1	,,
40 mm. to 44 mm.	,, ..	1	,,
45 mm. to 49 mm.	,, ..	2	,,
50 mm. to 54 mm.	,, ..	1	,,
55 mm. to 59 mm.	,, ..	2	,,
80 mm. to 84 mm.	,, ..	1	,,
		166	

In the first seven categories (i.e. apart from the seven extra large ones at the end of the list), each group numbers about half the preceding one, viz. approximately 80, 40, 20, 10, 5, 2, 1. These nodules thus present in their sizes as measured by their maximum diameters a simple geometrical progression. This is shown graphically in text-fig. 5. Some of the smaller nodules superficially look rather like buckshot gravel, which is a pedological product and would indicate derivation from a land surface (Gill, 1953F). However, on grinding a surface on some of these it was found that they generally consist basically of bryozoa; they are as phosphatic as the rest.

Phosphatic nodules are found on the floors of present seas. Sverdrup, Johnson, and Fleming (1942) write, " In certain near-shore localities phosphorite $Ca_3(PO_4)_2$ forms a cementing material which accumulates in nodules and crusts. These phosphate nodules were first discovered by the *Challenger* off the Cape of Good Hope . . . Phosphorite is commonly associated with abundant calcareous remains and glauconite. Pelagic foraminifera and benthic remains may be found, and also the teeth and bones of fish and marine mammals.. The phosphorite nodules have a characteristic smoothly rounded surface with the upper surface having a glazed unweathered appearance." (pp. 1032-1033.)



TEXT-FIGURE 5.

All the smaller phosphatic nodules of the Hamilton district are glazed but not all the big ones. When glazed, they are glazed all over and not just on the upper surface. They vary from light to dark brown in colour. Some are greenish due to the presence of glauconite. Of the seventeen ground to show their internal structure, one was oolitic and the rest massive. They generally consist of marl cemented together with the phosphatic mineral. Two of the nodules had cavities containing uncemented marl.

Twenhofel (1950) discusses the various theories advanced to explain the origin of phosphatic nodules, and concludes, " The deposits were formed in place, they are in places where clastic sediments are not accumulating, and they are not erosion remnants ". At Hamilton the geological evidence shows that:—

1. The nodules probably formed in place because they cannot be satisfactorily accounted for as sedimentary materials. Terrigenous material is rare.

2. The time was one of non-deposition because the formation underneath is Balcombian and the one above Kalimnan with the Cheltenhamian (Upper Miocene) unrepresented.

3. The sea was not of great depth as is shown by the fossils. The sediments are shelf deposits, and they are glauconitic.

4. Conditions of chemical reduction obtained on the sea floor to form the glauconite, and the seas were probably alkaline (*cf.* Twenhofel, 1950). " Rich glauconite occurrences lie adjacent to land areas where plutonic and metamorphic rooks are exposed." Quartz porphyry outcrops frequently in the Hamilton area.

In order to test the fairness of the sample of nodules described above, excavations were made at various places on both sides of Muddy Creek. It was found that the nodules collected were typical, although in some places there was a higher proportion of elongate or cylindrical ones. Internal casts of a lamellibranch and two gasteropods were noted in the same phosphatic and ferruginous material; they likewise had rounded edges and were glazed. In places the nodule bed fades out. In Muddy Creek the bed has a dip of approximately 1° upstream.

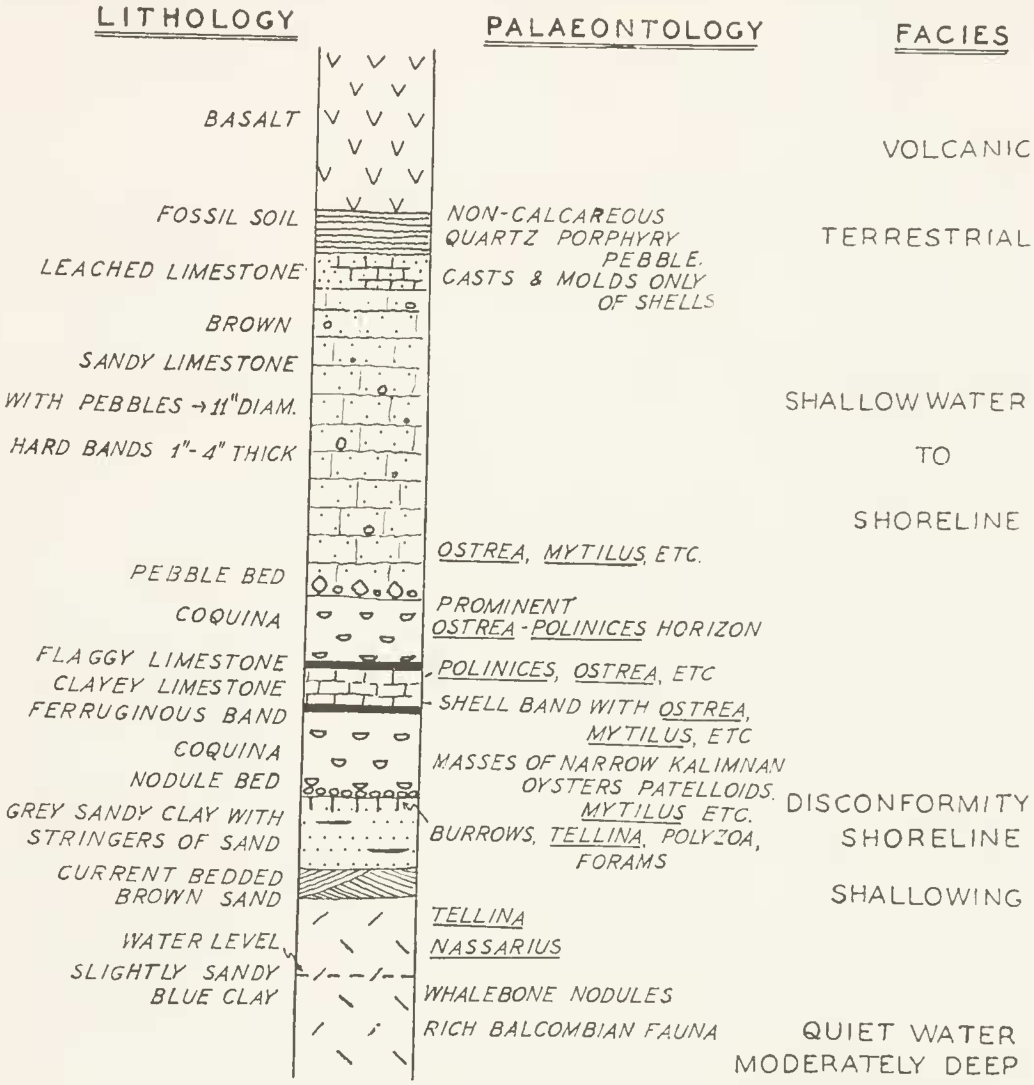
The largest nodule I have seen was collected by Dr. G. B. Pritchard from Grange Burn. It is of marly sediments about 7 inches long by 3 inches in diameter, cylindrical in general shape but slightly arcuate. It is pierced by numerous pholad burrows, commonly ¼ inch in diameter. In some cases fossil pholads still exist in the fossil burrows which have been infilled later with sediment. There are other smaller holes cut (see Turner, 1953) by boring molluscs. The nodule is highly phosphatic. Some nodules have epiphytic growths on them, such as one collected by W. J. Parr on which are numerous small corals. Phosphatic nodule beds have been described elsewhere in Victoria in the Geelong district (Coulson, 1932; Keble, 1932), at Beaumaris (Singleton, 1941), and near Princetown (Baker, 1945).

It is interesting to compare the Hamilton nodules with the authigenic phosphorite nodules described from off the Californian coast by Emery, Butcher, Gould, and Shepard (1952). Over 90 per cent. of the samples came from a submarine bank and much of the phosphorite was " nodular and polished as though in the process of formation ". " Broken and re-cemented pieces occur occasionally and several nodular specimens include pebbles of clastic material." Borings in the phosphorite are filled with recent sediments. These nodules are Quaternary in age but formed before the last glacial stage. Emery and Dietz (1950) have described phosphorite of Miocene age in North America, and Willcox (1953) has given an account of phosphatic beds in England. Both writers comment on the mode of formation of such deposits.

The nodule bed of the Hamilton district contains a large number of vertebrate fossils, including whales, sharks, and fish (represented by jaws, palates, and vertebrae). Stratigraphically, the nodule bed is Kalimnan in age, because although it rests on a formation of Balcombian age, it is itself part of the overlying Kalimnan formation. When the sample nodules were being extracted as described above, such typical Kalimnan mollusca as *Polinices cunninghamensis, Nassarius crassigranosus, Zenatiopsis angustata*, and *Glycymeris decurrens* were noted in between the nodules. However, a cast of *Aturia australis* (a Cheltenhamian or Balcombian fossil) was found in the nodule bed by Dr. G. B. Pritchard (Nat. Mus. Coll.).

In the National Museum there is a collection of 49 species of Kalimnan fossils and a highly phosphatic nodule from Goodwood station near Minhamite Railway Station 25 miles S.-E. of Hamilton (see text-fig. 1) proving the extension of the Pliocene beds some distance further south. There is also a small collection of Kalimnan fossils from a well at 170 feet at Goroke, 75 miles N.-N.-W. of Hamilton (pres. by Mrs. Ellen M. Harvey, 13.9.23).

The late Mr. W. J. Parr kindly drew the attention of the writer to the fact that the 1946 floods had washed out a section of Grange Burn, revealing the Tertiary beds further upstream than previously. Section 2 (text-fig. 6) was measured in November, 1950 on the south bank of Grange Burn at the site marked on the map (text-fig. 3). It will be seen from this section that below the nodule bed there is a zone with current-bedded sands and sandy lenticles in a clay bed. These structures suggest a shallowing sea. Quiet waters in which clay settled are replaced by disturbed waters with movement enough to transport sand and induce current-bedding in it. In this area the level of the nodule bed was surveyed over as great a distance as possible, and the average dip was found to be 0° 22″ downstream. This slight dip is shared by the beds above and below it as can be seen by their relation to the water level as one moves along Grange Burn.



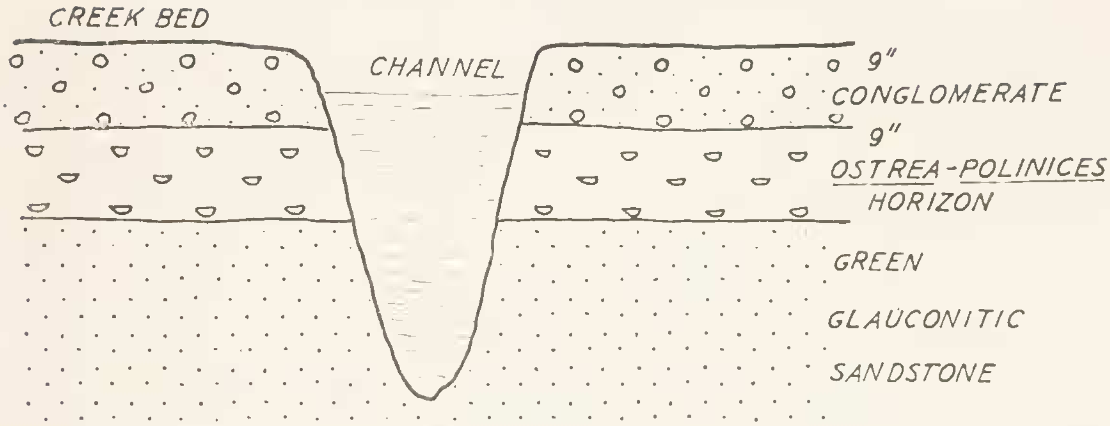
TEXT-FIGURE 6.—Section No. 2 on Grange Burn, near Hamilton, Victoria. From water level to the base of the basalt is 21 ft. 6 in.

About 275 feet east of section 2, a richly fossiliferous band outcrops in the creek bed with typical Balcombian fossils. On top of this, especially in the south bank, is a " nodule bed " of waterworn and glazed fragments of whale skeleton up to 1 foot long. Locally at least there are thus two nodule beds about 5 feet apart stratigraphically. No pieces of whale bone were found in the higher nodule bed in this vicinity, but if the underlying 5 feet of rock had been eroded bringing the two nodule beds together, we would have the typical nodule bed of other localities. In the Muddy Creek section there does not appear to be any deposit which can be equated with this 5 feet which could be regarded as a " zone of disconformity ". From the Balcombian marl one passes directly to the nodule bed and so the overlying Kalimnan as shown in text-fig. 10. The same applies to section 1 on Grange Burn.

Grange Burn Coquina.—This formation is extremely rich in shells both complete and broken, and many of them still retain much of their natural colour. On Muddy Creek the formation consists of the well-known shell-bed at MacDonald's Bank, but a greater thickness occurs along Grange Burn. The fauna consists of over 150 species of described mollusca alone, of which something like 10 per cent. are still living. The fauna is a shallow-water marine one, including molluscs such as patelloids, *Mytilus*, and borers. Parr (1941) has drawn attention to the presence of shallow water foraminifera in this formation.

There are extensive outcrops of quartz porphyry on Grange Burn opposite section 2. At locality 8 (see map, text-fig. 3) the creek flows over a small saddle in the quartz porphyry which separates the main mass from a fossil rock stack. No Balcombian beds were found outcropping upstream from this little waterfall, but there are Kalimnan beds of near-shore facies. About 130 yards upstream from locality eight and on the north bank there is quartz porphyry with holes infilled with ferruginous and fossiliferous conglomerate (loc. 9. See Pl. 4, fig. 3.). Near the porphyry the conglomerate is very heavy with boulders as much as 15 inches in diameter but generally less. Further away the conglomerate is not so heavy. The conglomerate is very poorly sorted with all grades of material. The contained pebbles are mostly porphyry but there are some of the greensand on which the conglomerate rests, showing penecontemporaneous erosion. The material of fine conglomerate size is commonly of milky quartz, while the sand fraction is chiefly clear and milky quartz and calcareous matter. The fossils are oysters (which are numerous), calcareous worm tubes, and gasteropods.

A typical section in the north bank of Grange Burn between localities 8 and 9 shows 4 ft. 6 ins. of current-bedded calcareous marine sandstone resting on 2 feet of conglomerate. The floor of the creek here consists of this conglomerate but the corrosion of channels reveals that the succession is as shown in text-fig. 7. Mr. G. Baker kindly confirmed that the greensand is glauconitic. Where oxidized, it assumes a fawn colour.

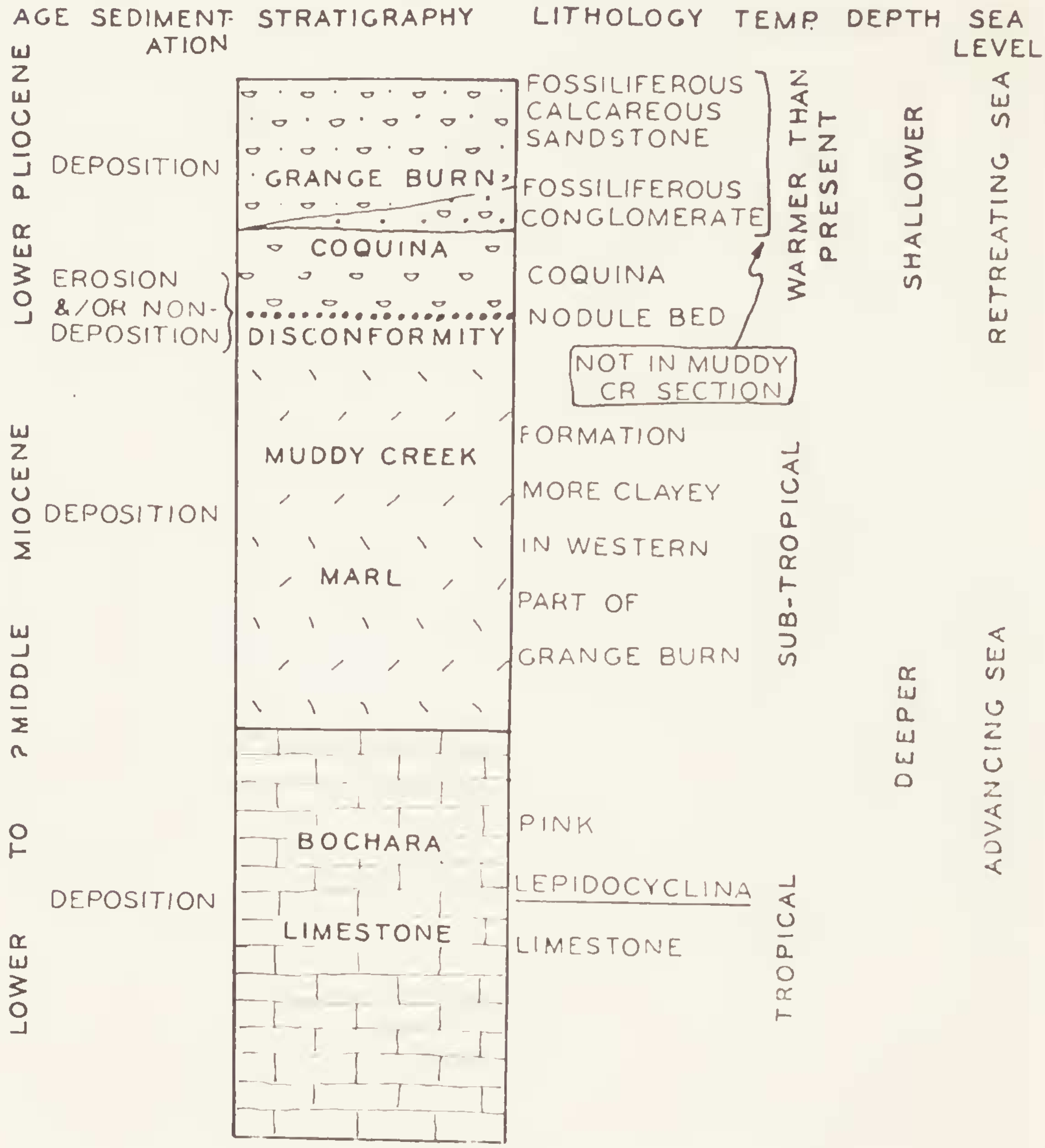


TEXT-FIGURE 7.—Section on Grange Burn, near Hamilton, between localities 8 and 9.

Summary of marine facies.—The geology and palaeontology done in this area are only a fraction of what remains to be done, but sufficient examination of the rocks has been made to understand the succession and the general facies of the various formations. This information is summarized in text-fig. 8. The lowering of temperature with time suggested by the fossils is to be checked by O^{16}/O^{18} analyses. The shallowing of the sea is evident from the development of conglomerate, current-bedding, glauconite, and shoreline forms of life. This disconformity between the Muddy Creek Marl and the Grange Burn Coquina is a sedimentary break representing upper Miocene time, more or less.

Ecologically, it is not likely that any bones of terrestrial animals would be found in the Muddy Creek Marl, but it is more likely in the near-shore to shoreline beds of the Grange Burn Coquina. As already stated, a piece of kangaroo jaw was found in this formation at Forsyth's Bank (Colliver, 1933; Singleton, 1935; Gill, 1953A, B; 1955).

Terrestrial Facies.—At locality ten (see map, text-fig. 3) on Grange Burn there is a fossil "podsol" soil with calcareous nodules underneath the basalt which blankets all the Tertiary beds described from the Hamilton district. In this soil are the roots of trees in position of growth (Pl. 4, fig. 1), and casts of branches have been found in the basalt. All the woods seen were softwoods. One sample was identified as probably *Phyllocladus* by W. D. Ingle of Forest Products Division of C.S.I.R.O. The two largest trees noted were those having root complexes 20 ins. wide by 6 ins. thick, and 17 ins. by 4 ins. The largest single root measured had a diameter of 7 ins. in one direction by 4 ins. at right angles to the first diameter. The wood has been coalified in some places, the water probably having been expelled by the pressure and heat of the basalt above. Baker (1950) also noted this wood. Mr. J. H. Willis has informed me that he found a log of *Phyllocladus* in Grange Burn about a foot in diameter and 5 to 6 feet long.



TEXT-FIGURE 8.—Stratigraphy of the area west of Hamilton, Victoria.

There is a good deal of carbonaceous matter in lenticles under the basalt. Some of this was examined for pollen by Dr. Isabel Cookson. No pollen was found but the material contained plentiful plant fragments.

Lacustrine facies.—Further upstream at locality eleven (see map, text-fig. 3) there is a diatomite under the basalt, i.e. in the same stratigraphic position as the soil with *Cuscus* and *Phyllocladus*. The diatomite is underlain by a grey clay which merges into a black clay containing plentiful pollen spores and fossil leaves (for section see Gill, 1953D). The following diatoms have been recognized in the diatomite (Tindale, 1953; Gill, 1953D).

Cocconeis placentula.
Cymbella gastroides.
Epithemia zebra.
Eunotia lunaris.
E. pectinalis.
Gomphonema intricata.
Melosira crenulata
M. granulata.
Navicula viridis.
Stauroneis anceps.
S. phoenecenteron.
Surirella fragments.

The above is a freshwater flora. *Cymbella* is an exclusively freshwater genus (Taylor, 1929).

In the carbonaceous clay under the diatomite *Acacia*-like phyllodes have been recognized (Cookson, 1954). Dr. I. Cookson, Dr. S. L. Duigan, and Miss K. M. Pike have recognized the following flora from pollen grains and spores:—

Acacia myriosporites.
A. octosporites.
Araucariacites australis.
Casuarinidites cainozoicus.
Dacrycarpites australiensis.
Dacrydiumites florinii.
Gleichenia circinidites and other fern spores.
Haloragicidites haloragoides.
Myrtaceidites eucalyptoides forma *convexus.*
Triorites harrisii.

Dr. Cookson writes, "There is every reason to believe that in the Hamilton and Daylesford regions a mixed conifer-*Eucalyptus* forest was not far removed from the seat of sedimentation." The conifers dominated the flora but not as completely as the eucalypts do now. The absence of *Nothofagus* invites comment. Living species like well-drained slopes in an area of plentiful rainfall, and probably the fossil species did too. At the Yallourn brown coal open cut there is an exceptionally good opportunity of studying the flora, but most of the wood and leaves are of conifers, although *Nothofagus* pollen is common. The interpretation of this situation is that the conifers occupied the lowland areas, while *Nothofagus* clothed the slopes of the surrounding hills (Cookson, 1945). Similarly, in the Tertiary lignites at Kiandra in the Snowy Mountains area of New South Wales there is plenty of *Nothofagus* pollen, but no leaves or wood belonging to that genus were found. The leaves were of lauraceous and coniferous types and the woods were coniferous (Gill, 1954A). Again it is to be inferred that the conifers and lauraceous types lived along the waterways while *Nothofagus* grew on the hill slopes round about. Although not present at Hamilton, *Nothofagus* is plentiful in other Pliocene deposits in Victoria, and it still occurs in the mountains in suitable habitats. The reason for its absence at Hamilton may be the flatness of the terrain. There was an adequate rainfall but no well-drained slopes where it could flourish. This interpretation is supported by the absence of such detritals in the sub-basaltic deposits as one could consider to be derived from the nearby Grampian Mountains. It may well be that they were uplifted in the Upper Pliocene when the countryside was faulted and the basalts outpoured.

Apart from the absence of *Nothofagus*, the flora at Grange Burn is quite typical of the Upper Tertiary. A flora consisting of conifers plus broad-leaved types (the so-called *Cinnamomum* flora of some writers) is typical of the Tertiary in Australia, and has often been called the Miocene Flora, although Sussmilch (1937) thought its date even later. Hills (1938) gave reason to think that it extended from Oligocene to Pliocene. The writer (Gill, 1952) showed that it ranged from Palaeocene to Upper Pliocene—the whole span of Tertiary time. Fleming (1953) has hinted that the presence of *Heligmope dennanti*, a pelagic gasteropod genus found in other parts of the world too, may mean that our Kalimnan beds include more than Lower Pliocene. If this prove to be so, then the terrestrial and lacustrine sub-basaltic facies in the Hamilton area are higher still in the Pliocene. On the other hand, they are definitely not Pleistocene, for none of the conifers so characteristic of the Tertiary have been found in the Pleistocene. *Cuscus* belongs to tropical Australia (Cape York Peninsula) and New Guinea, and it would be very difficult to picture this animal here in the Pleistocene.

Sponge spicules are common in both the diatomite and the carbonaceous clay. Some of the carbonaceous claystone was boiled in nitric acid for two days, then washed and dried. From the remaining sediment spicules belonging to the Spongillidae were picked with a fine brush. They are of two kinds—a size such as is found in most freshwater deposits, and then an exceedingly fine and delicate type of spicule. The spicules are very numerous indeed, indicating a rich sponge fauna.

A Pliocene lacustrine deposit similar to the Hamilton one has been described from Stony Creek near Daylesford in Victoria (Orr, 1927; Coulson, 1950). Diatomite, and pollen-bearing carbonaceous clays with leaves and sponge spicules occur there.

Palaeoecology.—A reconstruction of the terrestrial and lacustrine facies of Upper Pliocene time in the Hamilton area is presented in text-fig. 9. The pluvialty and warmth of the climate are indicated by the Tertiary flora, the wealth of ferns in a flat terrain where there could be no deep fern gullies, the leached soil, the presence of lakes, and the wealth of carbonaceous matter and pollen. *Cuscus* is an inhabitant of warmer and wetter parts than the Hamilton area is now with its temperate climate and rainfall of 26·98 ins. (average of 73 years. See Hounam, 1949.) The nearest home of the cuscus is now 1,700 miles further north in the tropics. Apart from the cuscus, there is no reason to think that the climate was tropical, and probably can best be estimated to have been a warm temperate one and pluvial.

The depth and nature of the lacustrine sediments shows that the lake waters were quiet and shallow. The large quantity of vegetable matter would develop conditions of chemical reduction on the lake-floor. The wealth of diatoms and sponges indicate that silica, calcium, carbonates, and nitrates were in solution as these are necessary for their metabolism. The bedrock of highly-calcareous rocks would ensure the presence of carbonates and neutralize any acidity, so that one might expect the waters to be neutral or even on the alkaline side. Recent work shows that the alkalinity of the waters is an important factor for some diatoms at least (Knudson, 1954). The sea had recently retreated from this area but was probably at some distance when this lake was in existence because there have been found no Hystrichosphaerideae which are so common in deposits near coasts (cf. Cookson, 1953), and no pollen of salt marsh plants such as chenopods. The flat coastal plain would provide a limited number only of biotopes.

The podsol soil has no buckshot gravel or iron pan in it, and this is due no doubt to the inhibitory effect of the highly calcareous parent material (Gill, 1953F). Iron is scarce in this environment.

TEXT-FIGURE 9. Diagram summarizing present knowledge of the terrestrial and lacustrine facies of Upper Pliocene time in the Hamilton area, Victoria. Basalt flows buried this terrain.

There are streaks of iron minerals in the fossil soil now, but these are obviously from the overlying basalt. In places there are streaks of greenish-yellow which could be nontronite, also derived from the basalt. The original soil was highly leached, being sandy (mostly clear quartz) at the old land surface (a loipon from the limestone), and with numerous calcareous nodules at 32 ins. from the surface and further down. The nodules are rounded and commonly about 4 cm. in diameter. The limestone in which the podsol is developed consists of 50 per cent. $CaCO_3$ at the subsoil level. Professor G. W. Leeper kindly described samples from the profile as follows:—

A. Very sandy loam.

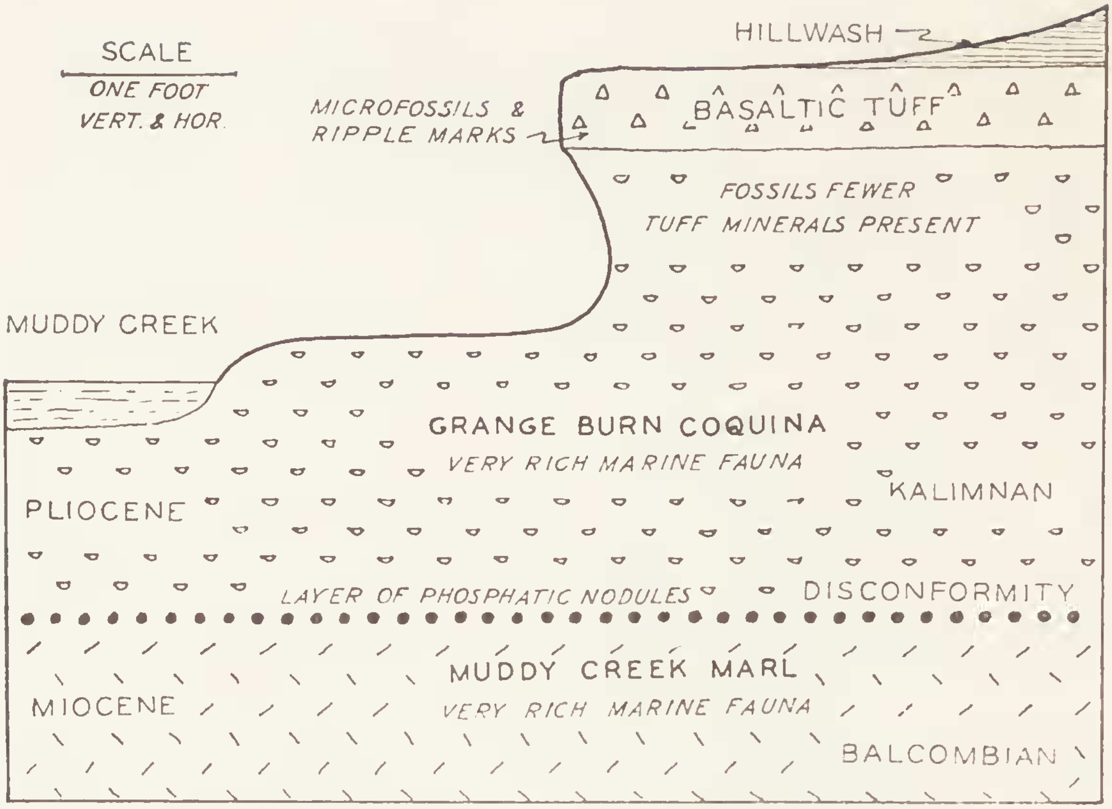
B. Sandy clay loam to clay loam, mottled, with light-coloured limey patches ¼ in. to ½ in. in diameter.

There is an enrichment in the B horizon in both clay and lime. The limestone on which this soil is developed must have been reduced in thickness by the process of soil formation.

Fragments of the carbonaceous clay from the lacustrine deposit were heated in a crucible. Upon oxidation of all the carbonaceous matter, the remaining material was rather like pottery, this texture being due to the fusion of the numerous sponge spicules. Three of the fragments were white and two a pale-fawn, illustrating the poverty of iron in this formation. If the lake waters were alkaline they would dissolve relatively little iron. " The solubility of iron at pH6 is about 10^5 times greater than at pH8·5 " (Mason, 1952, p. 140).

Terrestrial Facies in Muddy Creek Section.—On moving upstream from the Balcombian beds at Clifton Bank on Muddy Creek, one comes to MacDonald's Bank with the nodule bed forming the base of the Kalimnan deposits. The Kalimnan coquinoid here is just like that above the nodule bed at section 2 (see text-fig. 3), and many other places along Grange Burn. However, on passing further up Muddy Creek and so higher stratigraphically, instead of encountering the calcareous sandstone seen on Grange Burn, one is confronted with a light-grey basaltic tuff, as shown in text-fig. 10.

The tuff is 11 inches thick in the measured section, but is much thicker than this. On account of hillwash, there are no outcrops by which the succession can be followed up the side of the valley. The tuff is stratified and dips 1° upstream as does the nodule bed. Apparently the slight tilting of the beds took place after the tuff was deposited.



TEXT-FIGURE 10.—Section on south bank of Muddy Creek, near Hamilton, Victoria, at the east end of MacDonald's Bank (locality 1 in text-figure 3).

In the marl immediately under the tuff some volcanic minerals were found. The light minerals are fine-grained, and consist mostly of well-rounded quartz and of mica. The heavy minerals are of very small grain size, and include hackly olivine and augite. Zircon, tourmaline, chlorite, and black opaques are present. The small quantity and fineness of the basaltic tuff minerals in this bed suggest minor or distant volcanic activity. However, the stratified tuff which overlies it indicates strong volcanic activity. There are numerous marine microfossils and a few macrofossils in the lower part of this tuff, and some ripple marks, showing that the tuff was laid under water. No quartz can be seen in the tuff in hand specimen but some was found on microscopic examination. Olivine is a very common constituent.

In the National Museum there is a piece of tuff whose label reads, "Presented by Rev. Mr. McFarlane, in March, 1877. Muddy Creek, 4 miles from Hamilton". This tuff contains plants in position of growth vertically through the stratification. In addition there are fronds of a *Blechnum*-like fern horizontally along a bedding plane. J. H. Willis, of the Melbourne Herbarium says this form does not belong to any species of *Blechnum* growing in Australia at the present time. "There are no living representatives with the secondary lateral veins so close (3-4 per mm.)." The matrix has the appearance of a very fine silt, but on decanting proved to have practically no clay. Nevertheless the material acted somewhat like a clay in that it stuck to the evaporating dish and cracked on drying. This appears to be due to the large percentage of chloritic material present. The light fraction is mostly chloritic material and quartz is very rare. Mica is present. There is a small assemblage of heavy minerals, which are angular. Fresh, sharp-edged grains of olivine are common and the opaques include magnetite. No zircons were seen. There are cloudy grains which are probably altered mica. I am much indebted to Dr. A. W. Beasley for considerable help with the mineralogical work. The matrix of the fossil fern is thus a very fine tuff and a swampy or lacustrine ecology is indicated. This sample may well belong to the higher part of the tuff formation where weathering had taken place (hence the chloritic material), and ferns were growing. The amount of weathering shows that there was a break between the deposition of the tuff concerned and the emplacement of the rock now above it—probably the basalt. A sample of this tuff was washed for microfossils but none were found, not even a sponge spicule. Further field work will no doubt elucidate the succession, but there is enough evidence to say that a volcano was active nearby so that tuff was ejected into the sea, but during the deposition of the tuff, the sea retreated so that ferns grew where earlier marine fossils were deposited. The thickness of the tuff does not seem to account for this retreat of the sea, and tectonic uplift provides a more feasible hypothesis.

The lack of sedimentary evidence for the presence of the Grampian Mountains at that time (p. 150), and the evidence of uplift and faulting associated with the vulcanism in this area, prompt the idea that the Grampians were elevated in Upper Pliocene time.

On Grange Burn a calcareous sandstone overlies the Kalimnan shell bed and underlies the basalt. There is no tuff. On Muddy Creek, the tuff overlies the Kalimnan shell bed and underlies the basalt. There is no calcareous sandstone. The site of the buried soil with fossil Cuscus is only a little over a mile in a direct line from MacDonald's Bank on Muddy Creek where the tuff occurs. The fact that no tuff bed occurs on Grange Burn suggests that the volcano was rather to the south of Muddy Creek. However, a sample of the soil in which the Cuscus tooth was found was examined mineralogically to see if there were any trace of volcanic ash. Quartz is the commonest mineral, and the grains are sub-angular. There are hackly olivine grains like those found in the Muddy Creek tuff. The opaques have some grains angular and some rounded. Tourmaline is present, and zircons, which are small. White mica and carbonaceous material are obvious constituents. There is thus evidence that some volcanic ash fell on the Grange Burn area but not enough to form a tuff deposit.

The whole of this late Tertiary terrain was later sealed off with widespread basalt flows.

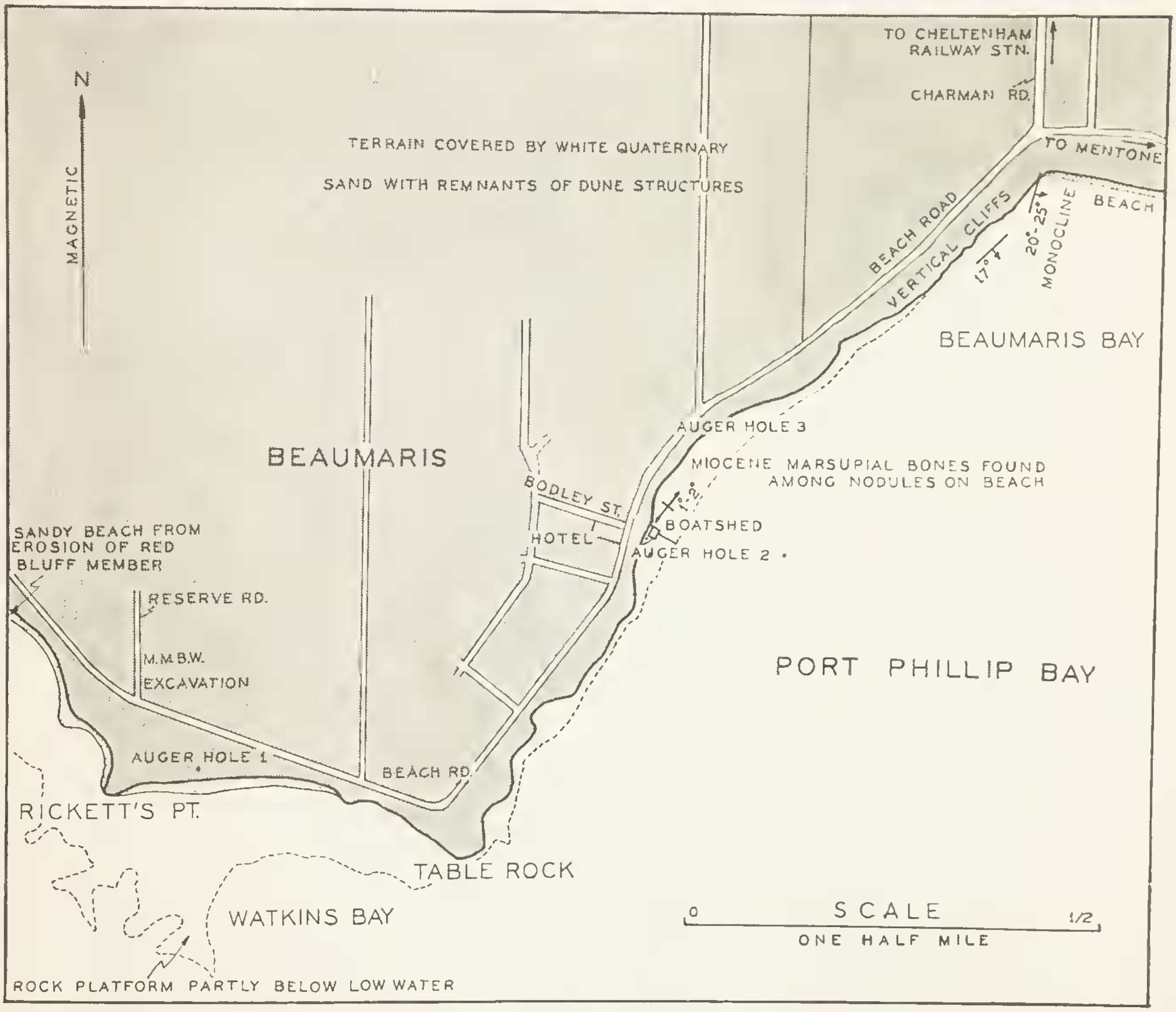
Environment of the Hamilton Fossil Marsupials.—

(*a*) *The Macropod.*—This kangaroo lived in Lower Pliocene time in a warm temperate or sub-tropical climate, as is indicated by the rich marine fauna with warm water elements. The animal was washed out to sea where a portion of the ramus was preserved in a shallow water marine coquinoid. This is the only evidence of Lower Pliocene marsupial life found so far in Victoria.

(*b*) *The Cuscus.*—A warm temperate or sub-tropical rain forest covered what is now the Hamilton District in Upper Pliocene time. Some ecologists would call such a forest a wet sclerophyll forest, retaining the name "rain forest" for one entirely without *Eucalyptus*. The forest at Hamilton was chiefly a coniferous one, but the eucalypts, wattles, and she-oaks that characterize the extant flora were also well represented. Ferns were common. Freshwater lakes were rich in diatoms and sponges. The terrain was flat and swampy, and the underlying limestone was leached to give a "podsolic" soil, not a *terra rossa.* The tooth of a cuscus found by the writer in the buried soil under the basalt is the only vertebrate fossil discovered so far. The living cuscus is a rain forest inhabitant in tropical areas, occurring "from Timor and Celebes through New Guinea to the Solomons and Cape York. . . In addition to a diet of leaves and fruit, it is said they will catch and eat birds and other small animals." (Troughton, 1951.) The presence of *Cuscus* at Hamilton fits in with the evidence for a climate warmer and wetter than the present.

C. Occurrence of Tertiary Marsupials at Beaumaris, Victoria.

The sea cliffs at Beaumaris are different from those found elsewhere on the east side of Port Phillip Bay. Being more lithified than the rocks that form the sloping cliffs of most of the N.-E. shore of the Bay, they constitute at Beaumaris a small promontory with vertical cliffs. An asymmetrical pitching anticline brings up these rocks from their usual position near sea-level to form cliffs about 50 feet high. At Rickett's Point, ironstone outcrops between tide marks, then further east it rises gradually to form the cliffs at Beaumaris. The axis of the anticline is at



Text-figure 11.—Locality map of Beaumaris, Victoria, showing structure (after Hall and Pritchard 1897), the sites of auger holes, and fossil localities. Vertical cliffs occur where the Black Rock Member outcrops, and sloping cliffs with sandy beaches characterize the coast where the Red Bluff Member outcrops. The map is based on aerial photographs.

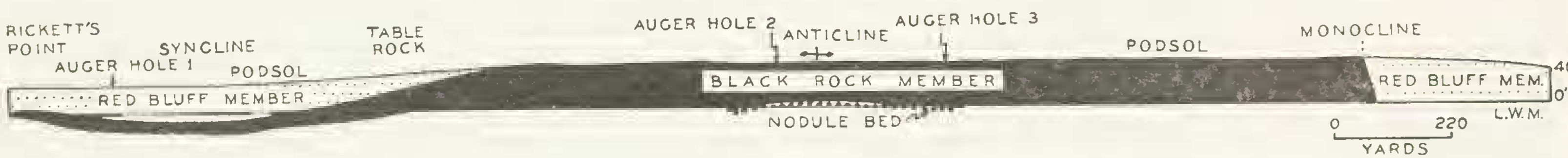
the Beaumaris boatsheds, then with a low dip of only a degree or two the beds dip towards Mentone. However, at the end of Charman-road the beds dip suddenly at 20° to 25° (strike E.25° S.) in a monocline, and thus disappear below sea-level. A short distance S.-W. of the monocline, the strike swings a little so that it is parallel to the shore from there to Table Rock. This swing in the strike can be seen by the curve of a reef of ironstone visible in the sea at low tide. The monocline is associated with a change in direction of the coastline, and with the sudden change from vertical cliffs of highly fossiliferous and ferruginous marine beds to more or less unfossiliferous, non-ferruginous softer freshwater beds which form sloping cliffs easily eroded.

The general structure of the beds at Beaumaris is shown in text-fig. 12, where the anticline and monocline are indicated in a diagrammatic section from Rickett's Point to Mentone Beach. The two types of beds referred to above have been included in the Sandringham Sands formation (Gill, 1950). The type section is Red Bluff, Sandringham. Since the above paper was written, the author has carried out further work on these strata, and it is clear now that the two types of beds at Beaumaris are two members of the formation which can be seen at Red Bluff and traced on through the suburbs of Melbourne to Keilor, a distance of some 25 miles. It is therefore here proposed that the following subdivision be recognized:—

Formation.	*Members.*
Sandringham Sands ..	2. Red Bluff (Younger) 1. Black Rock (Older).

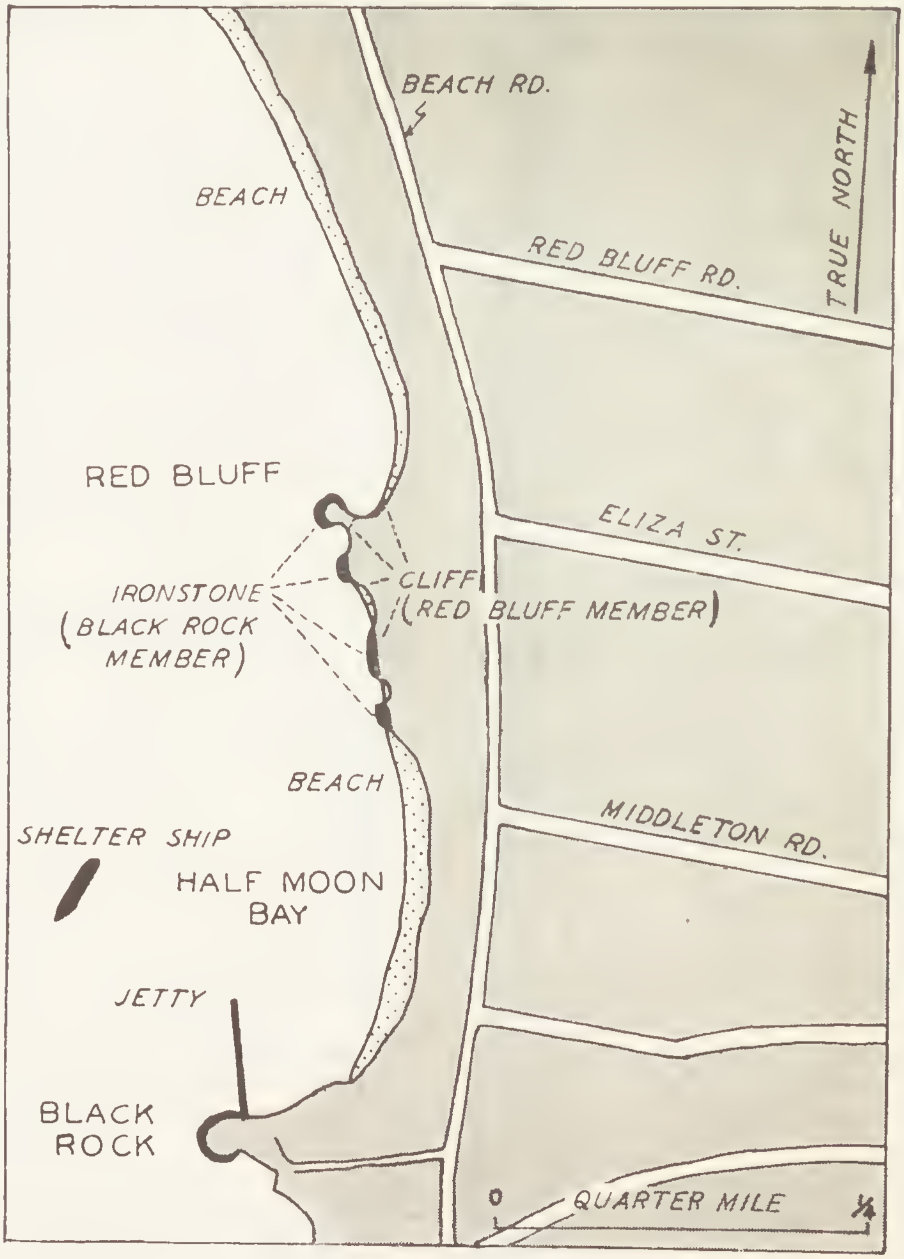
The stratigraphically higher Red Bluff member is a non-marine (mostly fluviatile) one, while the lower Black Rock member is marine. The definition of these members in the type section of the Sandringham Sands Formation at Red Bluff is shown in text-fig. 13.

1. *Red Bluff Member.*—This is named after Red Bluff, Sandringham, the type section of the Sandringham Sands formation. At Red Bluff it consists of about 78 feet of clayey sands, off-white to various pastel tints in colour, red being common and hence the name of the bluff. Generally speaking, the lowest part of the member consists of sands, the large median part of sands, gravels, and conglomerates, and the highest part of sands again. This three-fold subdivision of the member can be recognized all over Melbourne and is particularly well shown in many sections up the Maribyrnong River valley. Foundry molding sands are taken usually from the comparatively thin top and bottom sections which

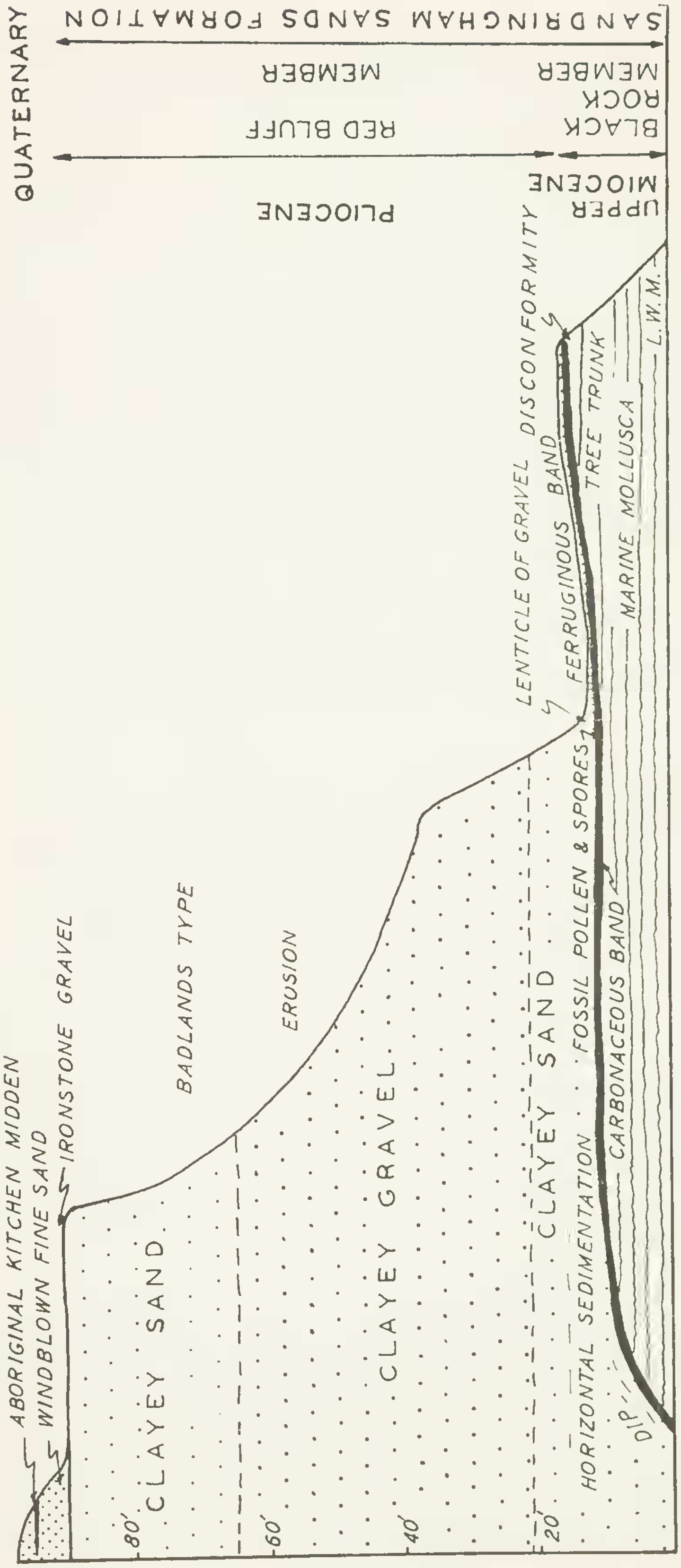


TEXT-FIGURE 12.—Diagrammatic section of coastal cliffs from Rickett's Point to Table Rock, to Charman-road, Beaumaris, Victoria, showing the author's interpretation of the relationships of the Black Rock and Red Bluff members in this area. There is a vertical exaggeration of nearly five times, so the dips are much steeper than in reality. For localities see Text-figure 11.

often consist of a fairly fine and well-sorted sand. Evenness of grain size is probably due to derivation from marine-sorted beds. Because these layers of desirable sand are comparatively thin, they have often been won by tunneling. In many places there are clay balls and clay lenticles in the median coarse section, and these sometimes contain fossil leaves. The clay lenticles, the presence of fossil wood, and the carbonaceous seams mentioned in the next paragraph are evidence of the non-marine origin of the Red Bluff member.



TEXT-FIGURE 13A.—Locality map, Sandringham and Black Rock, Melbourne, Victoria.



TEXT-FIGURE 13B.—Diagrammatic section at Red Bluff, Sandringham, type section of the Sandringham Sands formation. The subdivisions of the Red Bluff member are not well defined, and so are represented by broken lines.

Red Bluff consists of a high sloping cliff with a platform at its base. This platform is not due to a higher eustatic sea, but to differential erosion. The platform consists of the much harder Black Rock member on which is a seam of carbonaceous sand capped by a thin iron pan. The carbonaceous sand is the base of the Red Bluff member, but it has apparently held up percolating waters containing iron so that this has been deposited at that level. The top of the platform is not level, following slight dips of up to 5° in this iron pan. As shown in text-fig. 13B this carbonaceous seam cuts out near beach level. At its inland extremity it dips at various angles up to 15°. The overlying beds are practically horizontal so the dips are probably due to penecontemporaneous slumping. At the various points along the coast where the Black Rock member comes to the surface, this outcropping is due to low anticlines or inter-member erosion. The largest tectonic movement is that shown by the anticline and monocline at Beaumaris. The carbonaceous seam at Red Bluff is generally about 1 foot in thickness but it attains 2 feet in places. The carbon content varies somewhat, but from a sample collected by the writer, Miss Kathleen Pike was able to recognize the following:—

Hystrichosphaeridium tubiferum.
Cyathea and other spores.
Nothofagus species A of Cookson, 1946.
Nothofagus species F of Cookson, 1946.
Nothofagus species J of Cookson, 1946.
Myrtaceidites eucalyptoides forma *orthus.*
Fragments of cuticle and wood.

The *Hystrichosphaeridium* is a marine fossil (Cookson, 1953), but is often found in near-shore deposits, whence it can easily be wind-borne. The remainder of the forms are terrestrial. The ecology was probably that of a near-shore lagoon or swamp probably like the Albert Park Lake or Elwood Swamp in Melbourne before European settlement changed them.

The age of the carbonaceous seam is no doubt Tertiary as is indicated by the wealth of beeches and the fact that the species A, F, and J of *Nothofagus* have not been found in Quaternary beds. As the Red Bluff member rests disconformably on the Black Rock member which is Upper Miocene in age, the former can be taken to be of Pliocene age. The disconformity between the two members is the result of the erosive work of the sea as it retreated. A lenticle of carbonaceous material similar to that at Red Bluff was found at beach level at Hampton by Mr. H. T. Clifford (personal communication). Hart (1893) mentioned the one at Red Bluff and others at Mentone. The Victorian Mines Department (1938) put down four bores in the Yarra Yarra Golf Links near the corner of Warrigal and Centre roads, Moorabbin, 4½ miles inland from Port Phillip Bay. Bore 3 struck 5 feet of " ligneous clay " at 116 to 121 feet from the surface which is not far from the 150-foot contour of the Military Map. That the ligneous clay is found in only one of four closely spaced bores suggests that its occurrence is lenticular. The clay rests on a limestone. In the W. J. Parr collection in the National Museum are a couple of samples from a water bore put down in 1939 in the Victoria Golf Club's property, Park-road, Cheltenham, about 1½ miles from Port Phillip Bay. Over a marine limestone there occurred in this bore at 217 feet a grey, carbonaceous, non-calcareous siltstone with sponge spicules. Miss Kathleen M. Pike kindly examined this sample and was able to identify:—

Nothofagus spp. E, F, J of Cookson (1946).
Casuarinidites cainozoicus.
Myrtaceidites parvus.
M. mesonesus.
M. eugenioides.
Dacrydiumites mawsonii.
D. florinii.
Triorites harrisii.
?Epacridaceae.
Fern spores.
Hystrichosphaerideae.

It will be noted that this flora is of a type similar to that from Red Bluff. The driller's sample also included sandy material which contained shell fragments, foraminifera, ostracods, bryozoa, and plant remains. Small mollusca in the sample were filled with grey carbonaceous silt. The sample may well be evidence of a former shoreline lagoon where terrestrial and marine fossils mixed, such as in the Elwood Swamp area at the present time where marine shells are found admixed with material rich in pollen, spores, &c. (Cookson, 1954). It is interesting to note the occurrence of these carbonaceous horizons in the same area as the shoreline outcrops. More will be said later about the limestones and their age, but along the coast in this area and in river valley sections wherever the Red Bluff member is resting on other sedimentary rocks, these are invariably the Black Rock member. Keble (1950) described the Baxter Sandstones of the Mornington

Peninsula and regarded them (p. 42) as "the terrestrial phase contemporaneous with the Cheltenhamian". Other clays and sands were regarded by him as Pliocene in age. What the relationship is between the Baxter Sandstones and the post-Cheltenhamian Red Bluff member is not known, but it is possible that they are homologous.

2. *The White Sands.*—It will be noted from the section of Red Bluff in text-fig. 13B that the white sands at the top of the cliff are not included in the Red Bluff member nor are they given a formational name. They were similarly excluded from the definition of the Sandringham Sands formation (Gill, 1950). These white sands appear to be a pedological product or weathering residue or loipon from the breakdown of the underlying formation. Carroll (1949) found no mineralogical break between the rocks at Beaumaris and the overlying white sands. An indication of the age of the sands is given by the following considerations:—

(*a*) The white sands overlie both the Black Rock and Red Bluff members and therefore are younger. They cap the truncated Beaumaris anticline and so are later than the earth movements affecting the above two members.

(*b*) They do not occur on the Red Bluff member where it is covered by Newer Basalt, and the sands are therefore later than the basalt.

(*c*) The white sands have on them a podsol soil (Patton, 1933) which by comparison with other soils in Victoria dated by radiocarbon (Gill, 1953 E, F, 1954B) one would expect to be Holocene in age.

(*d*) The white sands have a dune topography, and so an aeolian origin. That the dune profiles are still fairly well preserved is an indication of recent formation. The dunes were formed in a time drier than the present, for they are now immobilized by vegetation.

While the white sands themselves have been in process of formation for a long time, they assumed their present form in a recent dry period. This could have been the mid-Holocene arid period of about 5,000 years ago.

3. *The Black Rock Member.*—The differences between the Red Bluff member and the underlying Black Rock member are summarized in text-fig. 14. The name of the latter member is from

SANDRINGHAM SANDS FORMATION.

Red Bluff Member.	Black Rock Member.
1. Sands and gravels, generally clayey	1. Sandstones to marly sands
2. Non-ferruginous	2. Ferruginous, commonly forming ironstone
3. Non-calcareous	3. Calcareous, or originally so
4. Lenticles and balls of pipeclay	4. No clay seams
5. Beds and lenticles of carbonaceous sediments	5. Non-carbonaceous
6. Not lithified	6. Lithified
7. Fossil wood, leaves, pollen, spores, freshwater sponge spicules; marine dinoflagellates in carbonaceous sediments at seaward end of member	7. Fossil whales, dolphins, sharks, rays, fish, cephalopods, mollusca, brachiopods, foraminifera, echinoderms, corals, polyzoa and crustacea. A few marsupial bones from one site
8. Cliffs sloping, and suffer badlands erosion	8. Cliffs vertical, and break off in sections
9. Pastel shades of grey, yellow, red, &c.	9. Yellowish-brown and reddish-brown to very dark brown
10. No stratification	10. Stratified
11. Current bedding common	11. Current bedding not characteristic

TEXT-FIGURE 14.—Comparison and contrast of the two members of the Sandringham Sands Formation.

the suburb of Black Rock which appears to have been named from an outcrop on the beach of the dark Black Rock member. The two members are alike in their high percentages of quartz, the grains of which are well rounded, having experienced a number of cycles of erosion. Carroll (1949) has given the following sand clay analyses:—

	Sand %	Clay %
White sands overlying Black Rock member at Beaumaris	75	25
Red Bluff member at Mentone . .	90	10
Black Rock member at Beaumaris . .	81	19

Carroll states that " Both the mechanical composition and the mineralogy of the Cheltenhamian beds at Beaumaris indicate that the source of the material was in pre-existing sedimentary rocks ". " Both lithologically and mineralogically there is a break in sedimentation between the Cheltenhamian beds and the presumably overlying white sandstone at Mentone." In other words, there is a clear mineralogical difference between the Red Bluff member and the Black Rock member. It should be noted that for convenience Dr. Carroll took the whole of the Black Rock member at Beaumaris as " Cheltenhamian beds ", but in his definition of this stage Singleton (1941) limited it to the lower 20 feet of strata because he could not find fossils in the upper beds and so could not determine their age.

In the type section for the Sandringham Sands formation at Red Bluff, Sandringham, the Black Rock member is represented by 6 to 10 feet of brown fine-grained sandstone from which Hall and Pritchard (1897) have recorded a fauna of sixteen marine species. The rocks are highly ferruginous and the " small lenticular sheets of a hard grey limestone " referred to by the above authors may appear calcareous but are not. The Black Rock member here owes its elevation above sea-level to a low anticline. At a number of places along this coastline the Black Rock member rises above sea-level, apparently elevated by rolls or low anticlines. Hall and Pritchard (1897) record fossils from some of these localities, one of which is Rickett's Point (see text-fig. 11), an ironstone outcrop included by Singleton in his mapping of the type Cheltenhamian outcrops. However, this appears to be the ironstone high in the type section near the boatsheds which Singleton (1941, p. 35) excluded from his definition of the Cheltenhamian, and if this be so, then the ironstone at Rickett's Point is not Cheltenhamian. If it is Cheltenhamian, then the rocks that form the lower part of the member at Beaumaris boatsheds here constitute the top of the member, and considerable erosion has taken place; also there has been lateral change in lithology. If the ironstone at Rickett's Point is Cheltenhamian, then the Red Bluff member rests directly on Cheltenhamian at Rickett's Point, but at the Beaumaris boatsheds there are some 20 feet of non-Cheltenhamian rocks on top of the Cheltenhamian which do not belong to the Red Bluff Member.

Between Rickett's Point and Table Rock is Watkins Bay which is interpreted as resulting from the dipping of the ironstone below sea-level before rising to form the Beaumaris cliffs. Near the centre line of this bay an auger hole was put down on the flat a few feet above high water level and behind the bathing sheds. The section proved was as follows:—

Auger Hole 1.—

0 ft. to 2 ft.—Dark-grey sand including carbonaceous matter and marine shells (*Subninella, Mytilus*). Remains of a small aboriginal kitchen midden. Band of shells at 16 ins.

2 ft. to 4 ft. 8 ins.—Fine yellowish siliceous sand similar to beach sand.

4 ft. 8 ins. to 5 ft. 9 ins.—Gravel and fine conglomerate. Consists of coarse quartz sand with quartz pebbles up to $\frac{1}{4}$ in. diameter, and ironstone pebbles up to 2 ins. diameter.

5 ft. 9 ins. to 12 ft.—Mottled light-grey and fawn, fine, slightly clayey sand which is weathered for the first foot and partly so for the next foot. Thereafter fresh until 12 ft. where it became darker, coarser, and too hard to cut with the auger. The ground water level stood at 8 ft. (14.10.54). Samples at various levels were washed and found to consist mostly of clear quartz sand, with occasional mica flakes. The clay percentage is very low, the binding agency apparently being the fine silt fraction.

The above section is interpreted thus:—

0 ft. to 5 ft. 9 ins.—Quaternary sediments.

5 ft. 9 ins. to 12 ft.—Red Bluff member with weathered surface (a juvenile soil).

12 ft.—Probably Black Rock member.

In recent years a number of excavations have been made in the Red Bluff member in this district for sewerage pumping stations (e.g., corner Beach and Reserve roads, Beaumaris) and drainage works, and the fresh material excavated is very similar to that found in the Watkins Bay auger hole from 5 ft. 9 ins. to 12 ft.

At the base of the Black Rock member is a nodule bed (Hart, 1893; Hall and Pritchard, 1897; Cudmore, 1926; Singleton, 1941) which is brought to beach level at the axis of the Beaumaris anticline. This nodule bed marks a disconformity. The bed under the nodule bed nowhere outcrops at the present time, and so two auger holes (Nos. 2 and 3) were put down to determine the nature and age of the underlying bed in the vicinity of the two points at which Singleton measured sections when defining his Cheltenhamian Stage.

Auger Hole 2.—On the Beaumaris beach west of the boatsheds and below the end of Bodley-street. If the line of the brick wall forming the rear of the boatsheds is extended 27 ft. west, a site is reached 3 ft. 9 ins. from the cliff where the auger hole was put down. Because of difficulty caused by the nodules, a hole was dug with a spade to 3 ft., and then continued with the auger. The section from beach level (not more than a foot above H.W.M.) was as follows:—

0 in. to 6 ins.—Cliff wash.

6 ins. to 3 ft. 3 ins.—Coarse, well-rounded, clear quartz sand with some concretionary nodules (probably from erosion of the nodule bed seaward of this point), and pebbles of marl and ironstone. Also waterworn *Lovenia*, *Monostychia* and *Ostrea*.

3 ft. 3 ins. to 4 ft. 6 ins.—Calcareous and ferruginous nodules with coarse quartz sand. Some of the calcareous nodules are much bored with marine borings, but no such borings were seen in the ferruginous ones.

4 ft. 6 ins. to 6 ft. 1 in.—Yellowish-brown marly sand rich in foraminifera and ostracods.

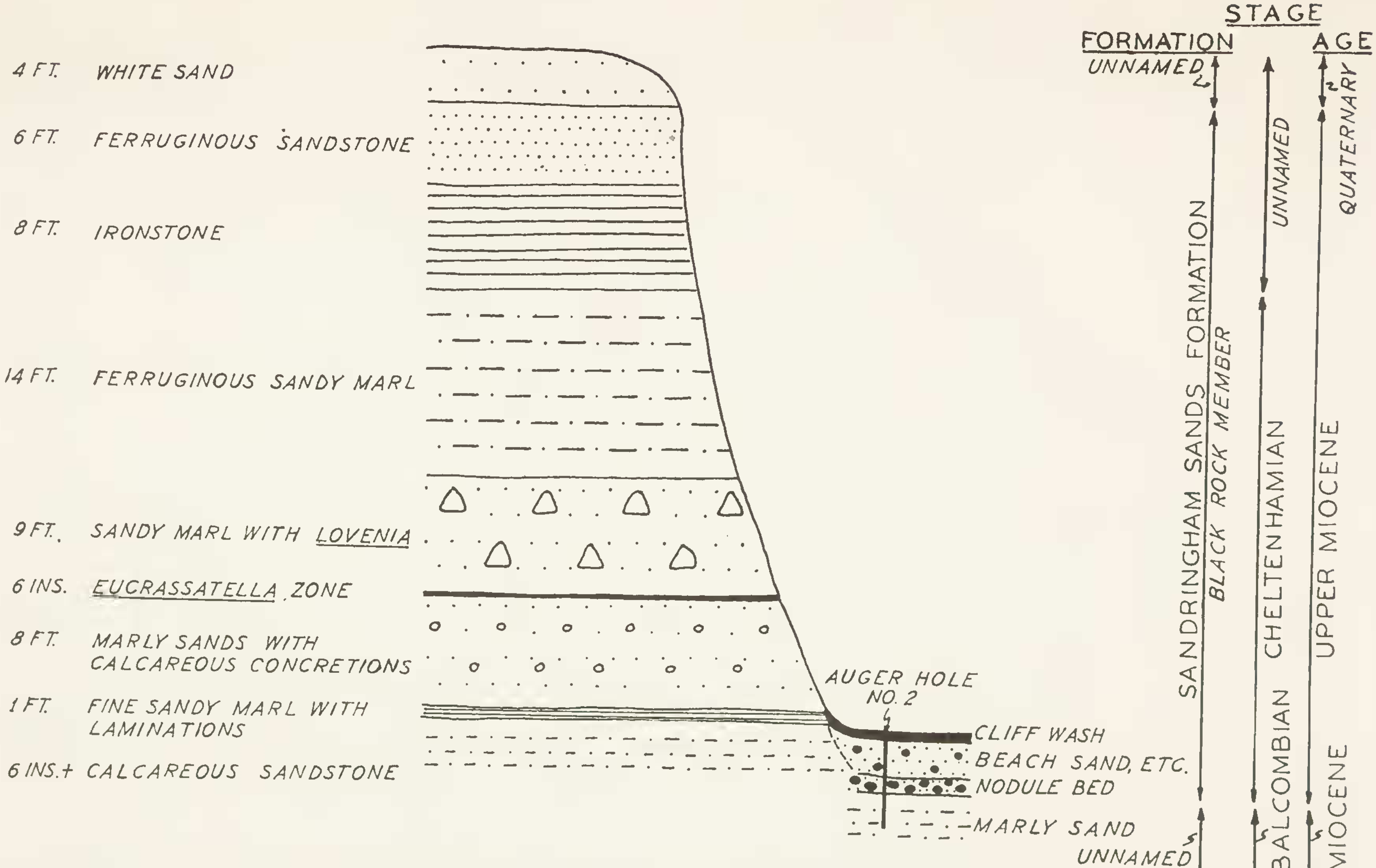
At 6 ft. 1 in. a hard calcareous band was encountered with water flowing over it. An unsuccessful attempt was made to punch through this band with a fencing bar.

Auger Hole 3.—On the Beaumaris beach near the former baths. From the path that descends the cliff, two rows of piles mark where a platform once led out to the baths. The platform ran for a short distance at an oblique angle to the cliff, then at right angles to the cliff straight out to the baths. The post marking the change of direction of this platform (25 ft. from the cliff) was used as a bench mark. Auger Hole 3 was 35 ft. east of this post and 15 ft. 9 ins. from the cliff. The beach level at this spot is below H.W.M. and so lower than that at Auger Hole 2. The section encountered was as follows:—

0 ft. to 1 ft.—Beach sand, concretionary nodules, and pebbles.

1 ft. to 5 ft. 9 ins.—Yellowish-brown marly sand as found in Auger Hole 2, with nodules.

In this section there was trouble with nodules jamming the auger, and the hole was abandoned eventually because of this difficulty. However, the succession was clarified. At both sites the nodule bed is underlain as it is overlain by marly sands. In text-fig. 15,



TEXT-FIGURE 15.—Section of sea cliff at the end of Bodley-street, Beaumaris, showing the type Cheltenhamian beds. The detail of the cliff exposures is after Singleton (1941), while Auger Hole No. 2 is that put down by the writer.

It may well be that the sediments under the nodule bed should also be included in the Sandringham Sands formation, but this question is left open until more is known about them.

Singleton's section west of the boatsheds is represented diagrammatically with the addition of the information from Auger Hole 2. The complete succession may be summarized thus:—

4 ft.—Quaternary whitish sands, windblown in part at least.
14 ft.—Highly ferruginous sands.
About 35 ft.—Brownish calcareous sands. Nodule bed.
2 ft. plus.—Yellowish-brown calcareous sands.

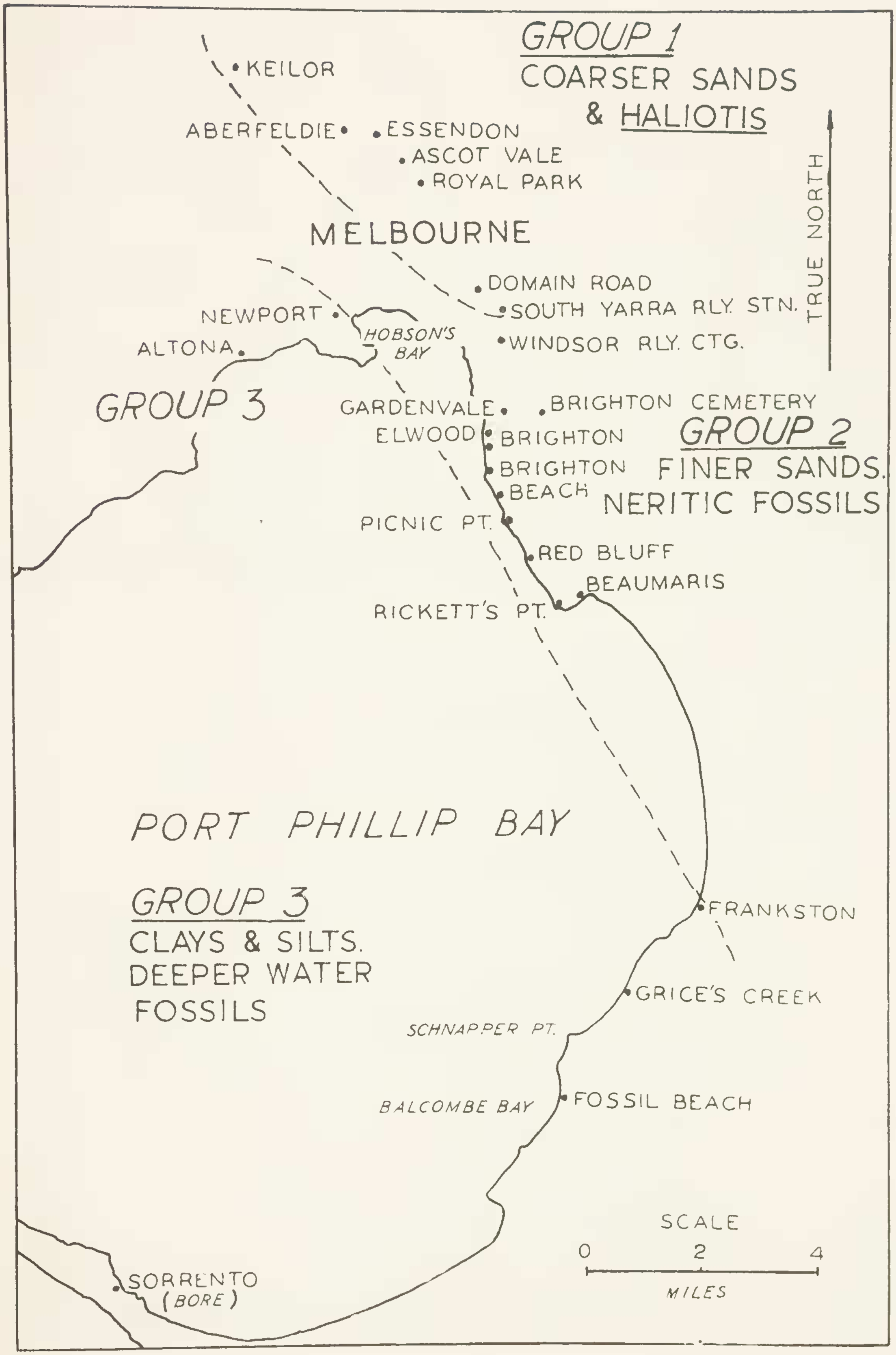
As the same type of sediment occurs above and below the nodule bed, the time taken to form it was not great enough for a change in facies to take place. There is a difference in the faunas above and below the nodule bed, but the difference in age is not a great one. The bed below the nodule bed is Balcombian (Singleton, 1941), while the nodule bed and above is Cheltenhamian. This marly sand facies of the Balcombian in intermediate between the calcareous clays of the type area at Balcombe Bay and the ferruginous sands and gravels (originally calcareous as shown by the numerous casts and moulds of molluscs) of the shoreline facies to be seen at Royal Park, Essendon, and Keilor (see text-fig. 16). The facies of the Black Rock Member is a near-shore one, as is shown by the nature of the sediments and the enclosed fossils. The sediments are sands and gravels (fine conglomerate in places) with admixed calcareous matter. Singleton (1941) said the sediments were glauconitic but Carroll (1949) claimed that she could only recognize nontronite. At spring low tide I dug a spade hole and extracted greenish marl sand which turned a fawn shade on drying. This colour change is probably due to nontronite, but in the same sample Mr. George Baker recognized glauconite. However, it is not plentiful. Glauconite forms in shallow waters. The presence of the bones of a number of land animals (the marsupials) also shows the site was near land. The marine fauna includes near-shore mollusca and barnacles. A fossil crab (P.15863) sent to Dr. M. F. Glaessner for identification proved to be *Persephona* sp. nov., a shallow water form. Evidence of appreciable currents is provided by rolled specimens of large bones (such as whale bones), pebbles, and current bedding (chiefly

TEXT-FIGURE 16.—Map showing the change from coarser to finer sediments in the Miocene marine Red Bluff member of the Sandringham Sands formation.

Group 1 localities have sandy sediments, often very coarse. They have the shoreline gasteropod *Haliotis*, and some have other shoreline forms such as *Turbo* and limpets.

Group 2 localities have generally finer sandy sediments, and while not possessing the above shoreline molluscs, have numerous shallow water fossils.

Group 3 localities are characterized by a calcareous silt to clay deeper water facies with appropriate fauna.


GROUP 1
COARSER SANDS
& HALIOTIS
KEILOR
ABERFELDIE
ESSENDON
ASCOT VALE
ROYAL PARK
MELBOURNE
TRUE NORTH
DOMAIN ROAD
SOUTH YARRA RLY. STN.
NEWPORT
HOBSON'S BAY
WINDSOR RLY. CTG.
ALTONA
GROUP 3
GARDENVALE
BRIGHTON CEMETERY
ELWOOD
BRIGHTON
BRIGHTON BEACH
GROUP 2
FINER SANDS.
NERITIC FOSSILS
PICNIC PT.
RED BLUFF
BEAUMARIS
RICKETT'S PT.
PORT PHILLIP BAY
GROUP 3
CLAYS & SILTS.
DEEPER WATER
FOSSILS
FRANKSTON
GRICE'S CREEK
SCHNAPPER PT.
BALCOMBE BAY
FOSSIL BEACH
SCALE
0 2 4
MILES
SORRENTO
(BORE)

in the higher beds). The Black Rock Member is marine throughout, but in the higher part of the sequence at Beaumaris, Singleton (1935) found fossil leaves which he referred to *Cinnamomum*. Plant remains have been found high in the same member associated with marine fossils at South Yarra, Royal Park, Ascot Vale, and Keilor (three localities in Green Gully were found by Mr. Ron Wilkins). A log of wood was found in the same stratigraphical horizon at Red Bluff (Hart, 1893). The leaves and wood are at the top of the Black Rock member, and with the sediments indicate a time when the waters were shallowing due to the retreat of the sea. This marine member is succeeded by the non-marine Red Bluff member.

Palaeontology.—Hall and Pritchard (1897) listed over 100 species of fossils from the Black Rock member at Beaumaris, and later writers have extended their list considerably. The late W. J. Parr (MSS) has listed the following foraminifera from the "*Neotrigonia* bed near base of cliffs, 300 yards east of baths":—

Amphistegina lessonii (derived).
Anomalina nonionoides.
Cibicides ingerianus.
C. lobatulus.
C. mundulus.
C. refulgens.
Dimorphina tuberosa.
Discorbis bertheloti.
D. turbo.
Elphidium crispum.
E. macellum.
E. striatopunctatum.
E. verriculatum.
Lenticulina orbicularis.
Orbulina universa.
Rotalia beccarii.
R. compressiuscula.
Siphonina australis.
Spirillina decorata.

Cudmore (1926) listed the vertebrates known from Beaumaris. They comprise two species of whales, a dolphin, 28 species of sharks, eight species of rays and sawfish, and two marsupials. In the National Museum Collection there are also some fish jaws (not yet described), and an earbone of a whale (P.16195) collected by Dr. G. B. Pritchard and determined by the British Museum for him as cf. *Balaena,* i.e., a whalebone whale, whereas those recorded previously are toothed whales. A collection of fossil teeth from Beaumaris made by D. K. Holloway includes *Oplegnathus manni* Chapman and Cudmore (1924, p. 145) which the authors described as restricted to the Kalimnan (including the Cheltenhamian stage which was erected later). The Knife-Jaw *Oplegnathus woodwardi* is still living in Australian waters. A further new record since Cudmore listed the fauna is that of an anterior tooth of *Squalodon* cf. *wilkinsoni* McCoy (P.16198) collected from the " basal beds, Beaumaris ", and presented to the National Museum by J. M. Wilson, 28th August, 1921 (see Singleton, 1935, p. 131). The following table sets out the fossils occurring at Beaumaris which appear to be of stratigraphical significance:—

Fossil.	Range.		
	Balcombian.	Cheltenhamian.	Kalimnan.
MOLLUSCA—			
Aturia australis NcCoy	—	—	
Limopsis beaumariensis Chapman	?	—	—
Neotrigonia acuticostata McCoy		—	—
VERTEBRATA—			
C.archarias collata Eastman		—	
C (Prionodon) javanus Martin	—		
Edaphon mirabilis Chapman and Cudmore*		—	
E. sweeti Chapman and Pritchard		—	—
Galeocerdo latidens Agassiz	?	—	—
Myliobatis moorabbinensis Chapman and Pritchard*		—	
Notidanus jenningsi Chapman and Pritchard*		—	
Nummopalatus depressus Chapman and Pritchard		—	—
Oplegnathus manni Chapman and Cudmore		—	—
Pristis cudmorei Chapman*		—	

* Known only from Beaumaris.

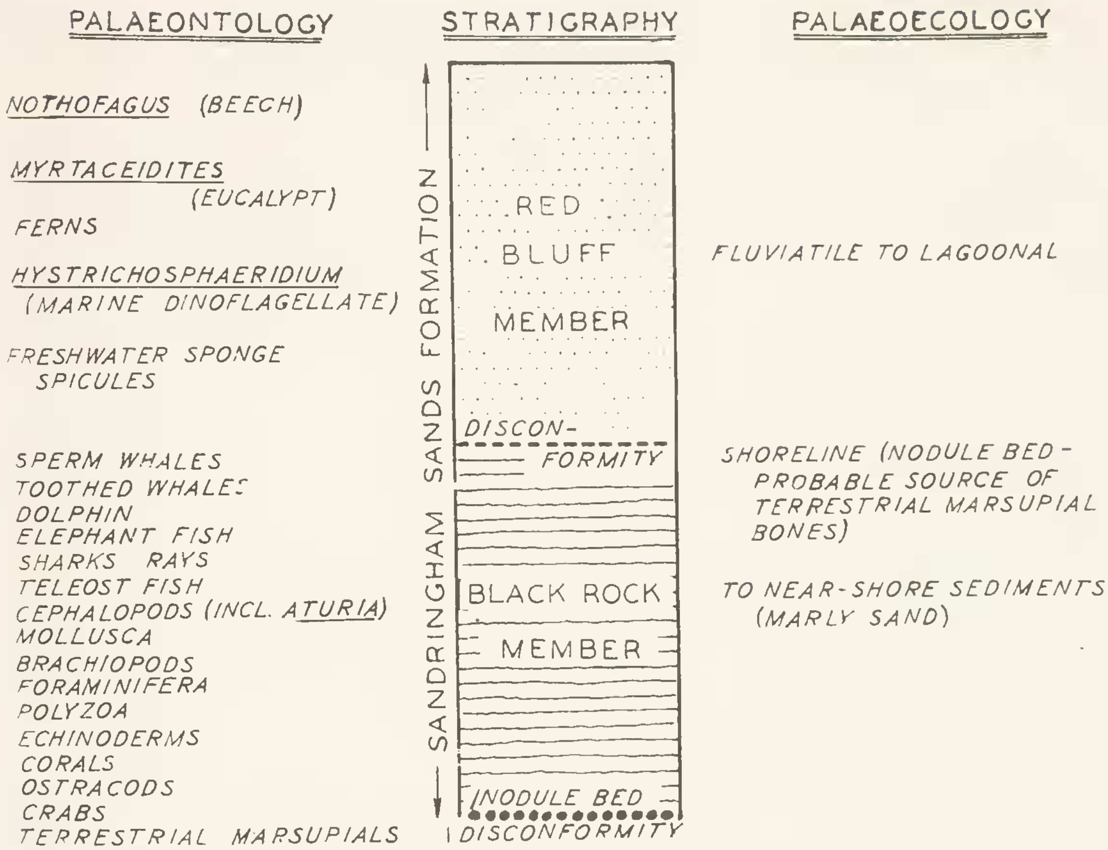
Most of the vertebrate fossils at Beaumaris appear to have come from the nodule bed which is a concentration of calcareous nodules, ferruginous nodules or pebbles, and vertebrate remains. The matrix is a coarse clear-quartz sand. The calcareous nodules are not phosphatic, but the ferruginous nodules are slightly so. The accumulation of derived nodules, and the coarseness of the sand matrix indicate the presence of comparatively strong currents. What thickness of beds (if any) was removed is not known. Probably a temporary shallowing of the sea caused erosion and so the aggregation of the nodules, then as the sea became deeper and quieter the coarse sand gathered, then the fine marly sand on top. A sample of this marly sand tested for phosphate showed a small amount present. The phosphate may be from the erosion of whale and other bones. A thorough mineralogical and chemical study of the nodule bed could throw a great deal of light on its history. The period of time represented by the nodule bed is probably small geologically speaking because:

1. On present knowledge there is no missing Stage between the beds above and below, as there is in the Hamilton district.

2. The sediments above and below the nodule bed are the same i.e., marly sand.

During the formation of the nodule bed the shore was presumably not far away, and this may well have been the time during which most of the marsupial bones were introduced into the sediments of the Black Rock member. If so, they can be dated very precisely.

Although vertebrate fossils are commonest in the nodule bed, they occur both above and below this horizon, as can be seen by the specimens used for the fluorine test. The holotype of *Scaldicetus macgeei* came from " 6 ft. to 10 ft. above H.W.M., Beaumaris " (Chapman, 1912). F. A. Cudmore collected a dorsal rib of a whale nearly 6 feet long from " the cliff near the point ", i.e., above the nodule bed. In the Cudmore Collection in the National Museum are sharks' teeth still in their matrices and thus providing some evidence of the bed from which they are derived. Allan Keefer found a large part of the skull of a toothed whale (P. 16204-16207) claimed to be " *in situ* on the sea bed beneath the jetty as it leaves the boatshed ". This fossil is encased in ironstone and so presumably comes from the ironstone band above the Cheltenhamian as defined by Singleton but still in the Black Rock member. The palaeontology and palaeoecology of the Sandringham Sands formation are summarized in text-fig. 17.



TEXT-FIGURE 17.—Summary of the palaeontology and palaeoecology of the two members of the Sandringham Sands formation.

Bore samples.—To the foregoing description of the Sandringham Sands formation and its members, there needs only to be added information from some bore cores before a review of the geological history is given. Reference has already been made to carbonaceous sediments in certain water bores put down in the southern suburbs of Melbourne. From a bore in the Victoria Golf Club's property in Park-road, Cheltenham, are samples given as from 217 feet and 221 feet respectively. Such bores are usually put down by percussion methods and the samples are not the most dependable. However, the sample from 217 feet consists of a piece of carbonaceous siltstone included in which are quartz grains, mica flakes, freshwater sponge spicules, plant remains, and what appears to be part of a seed case. With this non-calcareous siltstone are calcareous fossils such as foraminifera (large and small), shells, shell fragments, fine cidaroid spines, bryozoa, and marine ostracods, which were kindly determined by Mrs. Betty Kellett Nadeau as *Bradleya dictyon* (Brady).

Cytherelloidea sp., and *Cythereis* sp. Probably at about 217 feet there is a marine horizon, just above which is a lagoonal or similar facies from which the carbonaceous siltstone comes.

The sample from 221 feet in this bore is mostly coarse, consisting of rounded and angular pieces of clear quartz, milky quartz, grey quartz, and brownish quartz, the first predominating. Some grains are sub-spherical and highly polished; they are up to 3 mm. in diameter. Pieces of indurated siltstone, some containing minute pebbles, occur up to ¼ in. diameter and occasionally more. Small ferruginous pebbles occur in the siltstone and separately; they generally have a glaze. Most appear to be inorganic but some appear to have been internal casts of small fossils. Numerous foraminifera are so preserved, especially globigerinids. The sample also contains numerous pieces of broken and abraded molluscan shells up to ½ in. diameter. Fossils noted were pieces of marine mollusca, small marine gasteropods and lamellibranchs, bryozoa, marine sponge spicules, cidaroid spines, very numerous large foraminifera including *Lepidocyclina*, *Amphistegina*, and *Operculina*, and also small foraminifera including globigerinids. Crespin (1943) recorded *Lepidocyclina* (*Trybliolepedina*) *howchini* from " Victoria Golf Club, Cheltenham, at 221 feet ". The facies is clearly marine, and the pelagic globigerinids indicate access of the area to the open ocean. The numerous *Lepidocyclina* suggest a Batesfordian age, but they could be remanié in this particular bed as they are so worn. Different types of preservation also suggest that more than one horizon is represented. However, this sample is of great interest in that it provides evidence of the possible presence of Batesfordian sediments in this area, whereas at present the outcrop at Green Gully about 10 miles north of Melbourne (Crespin, 1926) is the only one recorded in the Melbourne area. Field work south of Keilor shows that Batesfordian limestone is more widely distributed in the Green Gully area than formerly thought.

Another bore of interest to the present subject is one put down in 1938 at the Kingston Heath Golf Links, also at Cheltenham. In the National Museum is a sample collected by the late W. J. Parr, and it comes from 136 feet. There are numerous large forams (as in the Victoria Golf Club bore), and a few small ones. Bryozoa are numerous. Fragments of mollusca, triaxial sponge spicules, and a marine ostracod (determined by Mrs. Betty Kellett Nadeau as *Cytheropteron*) are present. There is much coarse siliceous sand in the sample, nearly all clear quartz of mostly well rounded grains. Quartz pebbles up to ½ in. diameter occur, and calcareous pebbles up to 1½ in. diameter.

Parr (quoted in Singleton, 1941, p. 78) found " in the nodule bed and immediately overlying strata " some " worn and glauconite-filled remanié *Lepidocyclinae* ". No lepidocyclines have been found in the bed underlying the nodule bed and so they have probably come from the erosion of some bed further towards the shoreline of the times. Their source is probably the same as that providing the large forams in the two Cheltenhamian bores mentioned above.

General Geological History.—In Batesfordian times a tropical sea deposited sediments rich in lepidocyclines over the Batesford-Lara-Keilor-Cheltenham-Flinders area of southern Victoria, followed in Balcombian times by sediments in which these forms are comparatively rare. Enough outcrops are known of Balcombian deposits in the Port Phillip area to show a gradation from muddy to sandy to gravelly facies. At Beaumaris, the Balcombian beds of marly sand are capped by a nodule bed which represents a period of erosion, and then perhaps a short time of quiescence in which the ferruginous nodules were slightly phosphatized. The Sandringham Sands formation was next deposited —first the marine Black Rock member, which includes the type Cheltenhamian section. In the upper part of the Black Rock member are some very coarse beds becoming conglomeratic in places. At a number of localities leaves and wood have been found in the upper part of this marine member. The nature of the sediments and the included land plants suggest a shallowing sea. Disconformably above the Black Rock member is the non-marine Red Bluff member with lenticles of pollen and spore-bearing carbonaceous sediments, fossil wood, freshwater sponge spicules, and clay balls and lenticles containing *Nothofagus*-like leaves. Mild tectonic deformation then took place, and basalt was extruded over a wide area.

Tertiary Marsupials.—Over a long period of years terrestrial fossils have from time to time been found among the marine vertebrate fossils picked up on the shore platform at Beaumaris and nearby. None of the marsupials has been found *in situ*. Their preservation is like that of the Tertiary marine vertebrates found on the beach and *in situ* in the contiguous cliff. However, it was formerly thought that in Australia all the giant marsupials belonged to the Pleistocene, and so geologists were chary about accepting the marsupials as being Tertiary in age. With the introduction of the modern fluorine test it became possible to check the origin of the marsupials (Gill, 1953B), and the following are the specimens used along with the analyses obtained. The marsupials are described in the accompanying paper by Professor Stirton.

FLUORINE TEST ON TERTIARY MARSUPIALS FROM BEAUMARIS, VICTORIA.

A. Marsupial Remains *non in situ.*

Reg. No.	Fossil.	Data on Specimen.	% F.	% P_2O_5.	Fluorine Index
P 15909 .. 15910	*Nototherium* - like Diprotodontid	Brown, heavily mineralized portion of maxilla from "Beaumaris"	2·72	31·8	8·6
M.U.G.D. .. 2020	*Nototherium* - like Diprotodontid	Upper premolar with same preservation as P 15909. Reported in 1897 by Hall and Pritchard, one of whom collected it "some years before" at Beaumaris "loose among the pebbles on the beach floor"	2·62	28·4	9·25
P 15911 ..	*Sthenurus* - like kangaroo	Very dark brown, heavily mineralized, much abraded ramus of a mandible. Found by F. A. Cudmore at Beaumaris in the shingle at low tide level, 3rd February, 1913	2·70	30·9	8·75
P 15912 ..	Wallaby ..	Dark brownish-grey not heavily mineralized fragment of maxilla. "From Mr. Bailey. Loc. Cheltenham." 18th June, 1883	0·68	27·8	2·70
P 15908 ..	*Vombatus* ..	Brown, not heavily mineralized jaw fragment. "Found on beach between Cheltenham and Mordialloc." Presented by Mr. Newberry 12th November, 1868	1·90	28·5	6·65

B. Check Fossils.

Reg. No.	Fossil.	Date on Specimen.	% F.	% P_2O_5.	Fluorine Index.
P 15906 ..	*Isurus hastalis* ..	Dark brownish-grey mineralized bony base of a tooth of the upper jaw collected by F. A. Cudmore in 1936. "Remanié from clay bed under nodule bed." "Washed ashore just west of the ruined baths on to the shingle bank at dead low tide, Beaumaris"	2·83	31·2	9·05
P 15905 ..	*Isurus hastalis* ..	Enamel tip of same tooth P 15906	2·75	36·3	7·60
P 15907 ..	*Isurus hastalis* ..	Greyish-brown mineralized bony base of tooth of lower jaw (formerly called *Isurus retroflexus* but see Leriche 1926, pls. 31–32). "From nodule bed, east end of section." Coll. F. A. Cudmore	2·87	30·4	9·45
P 15904 ..	Vertebra of shark	Brown, mineralized. Collected at Beaumaris by Dr. G. B. Pritchard	2·68	32·5	8·25
P 15913 ..	Humerus of dolphin	Dark grey, heavily mineralized ..	2·82	28·3	10·0
P 15903 ..	Articulating bone of whale flipper	Brown, mineralized. Collected at Beaumaris by E. T. Jones	1·63	20·3	8·05

NOTES ON FLUORINE TEST.

1. The notothere and kangaroo remains (P.15909-15911, M.U.G.D., 2020) are shown to originate from the cliff which stands behind the beach at Beaumaris. The fossils collected on the beach have fluorine indices comparable with those of the fossils indubitably belonging to the Black Rock member of the Sandringham Sands. The marsupials are Tertiary (Upper Miocene) in age and belong to the Cheltenhamian Stage. The whale flipper has a lower index than any of the other bony fossils collected from the Black Rock member. It may be part of the whale whose rib Cudmore collected from above the nodule bed, and so is younger than the other specimens. The lower fluorine index for the comparatively impervious enamel of the tooth of *Isurus hastalis* as against the bony root is in keeping with general experience (Gill, 1955, p. 110). The two parts of the same tooth were included as a further test of this phenomenon. Generally speaking, the darkest bones are the more worn and have the higher percentages of fluorine, i.e., the dolphin, kangaroo, and sharks' teeth. Some collectors have regarded the dark (unoxidized) bones as coming from below the nodule bed and the oxidized bones from the nodule bed or above. Auger holes 2 and 3 show that at the cliff the strata are oxidized for some feet below the nodule bed. However, the rocks at spring low-tide level and below are unoxidized and so the dark fossils probably come from there.

2. The wallaby and wombat are not so mineralized as the other fossil marsupials, and their fluorine indices are much lower. The wombat remains came from the beach between Cheltenham and Mordialloc, i.e., an area in which the younger Red Bluff member and not the Black Rock member outcrops. The index is what one might expect for a fossil from the younger member. The fossil wallaby came from the beach at "Cheltenham". It is only of more recent years that Beaumaris has become a village. Before that the whole area was called Cheltenham after the nearest railway station. Charman-road runs directly from the station to the beach, and where it meets the coast is where the monocline forms the boundary between the Black Rock member and the Red Bluff member. The fossil wallaby therefore could belong to the latter member, but even so its index is so low as to make one refrain from claiming a Tertiary age for it. The best thing to do is to put it in the category of the "not proven". At Wynyard, Hamilton, and Beaumaris, the Tertiary marsupials occur in similar environments, viz., shallow water marine beds, sometimes with wood and leaves suggesting the presence nearby of a river.

D. Australia's Tertiary Marsupial Fauna.

Professor R. A. Stirton's paper (1955) on Tertiary marsupials from Palankarinna, South Australia, appeared as this work was about to go to press, so the fossils described therein are now included with those referred to in this paper to constitute the list of Australian Tertiary marsupials so far discovered. Professor Stirton regards the fauna from Palankarinna as Pliocene because a notothere from there has affinities with the notothere from the Upper Miocene of Beaumaris, Victoria, but is evolutionally more advanced.

Site.	Age.	Facies.	Marsupial.	Taxonomy.
Palankarinna, South Australia	Pliocene ? ..	Fluviatile	Bandicoot ..	*Ischnodon australis* Stirton
,, ,,	,, ..	,,	Wallaby ..	*Prionotemnus palankarinnaeus* Stirton
,, ,,	,, ..	..	Notothere ..	*Meniscolophus mawsoni* Stirton
,, ,,	,, ..	..	Koala	
Smeaton, Victoria ..	Pliocene or Pleistocene	..	Between native cat and Tasmanian Devil	*Glaucodon ballaratensis* Stirton
Mentone Beach, Victoria	Pliocene ..	..	Wombat ..	*Vombatus* ?
Grange Burn, near Hamilton, Victoria	Upper Pliocene	Terrestrial	Cuscus	
,, ,,	Lower Pliocene	Marine ..	Kangaroo	
Beaumaris, Victoria	Upper Miocene	.. ..	Notothere	
,, ,,	,,	,, ..	Giant kangaroo	
Wynyard, Tasmania	Oligocene or Upper Eocene	.. ..	Possum ..	*Wynyardia bassiana* Spencer

That all the giant Australian marsupials belonged to the Pleistocene was an idea previously accepted in Australia, but which must now be abandoned, as it is proved that nototheres and giant kangaroos were here in Tertiary time. Nor should this really occasion surprise because there were many giant placentals on other continents during the Tertiary.

The list of Australian Tertiary marsupials includes members of the following families:–

Diprotodontia	Phalangeridae.
	Phascolarctidae.
	Vombatidae.
	Macropodidae.
Polyprotodontia	Dasyuridae.
	Paramelidae.

This wide variety of forms suggests an early differentiation. The differentiation of the marsupials in Australia may well parallel the differentiation of the placentals on other continents.

The first glimpses of a stratigraphy based on the marsupials can be seen in this list. For example, the Upper Miocene notothere from Beaumaris is succeeded by the Pliocene notothere from Palankarinna, which in turn is succeeded by the Pleistocene *Nototherium* and *Diprotodon*.

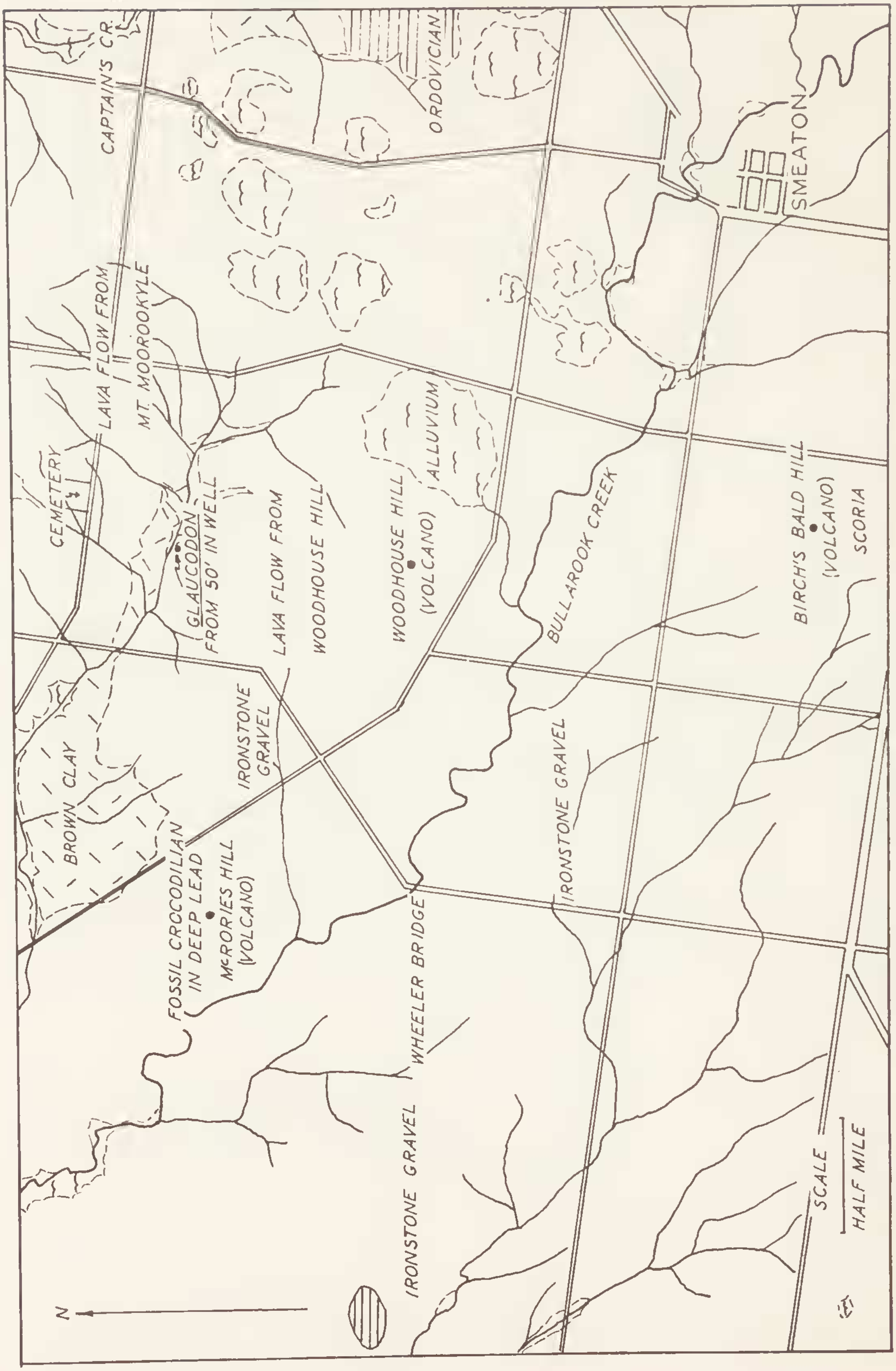
It has been asked why more Tertiary marsupials have not been found in Australia. The answer may be that many deposits considered Pleistocene because of the presence of giant marsupials or for other such inadequate reasons may be in fact Tertiary in age. Attention is now drawn to some such localities.

E. Some Possible Tertiary Marsupial Localities in Australia.

1. *One Tree Point, Tasmania.*—Johnston (1882), showed that the Derwent valley was occupied by a freshwater lake in Tertiary times. On pages 11 to 13 he gives an account of a section at One Tree Point, Hobart, where bone breccia was discovered in the joints of a lava flow. Johnston thought that this breccia was sealed off by another lava flow, and that it is therefore of the same age as the flows. Tasmanian geologists assign the basalts concerned an Upper Tertiary age. If Johnston's account of the occurrence of the breccia be correct, and if the basalts are correctly dated (there is no reason to doubt this), then the bones are of Tertiary age. Johnston recorded from the breccia a kangaroo-rat tooth determined as *Hypsiprymnus* (1882, figs. 63A-CC), and also " the well preserved incisor of an animal relating to the existing wombat." In an explanation of figures on page 50, there is listed a " fossil incisor of an animal probably allied to the existing *Halmaturus* from the bone breccia, One Tree Point." Figs. 65A-D comprise " various sections of a leg bone of a marsupial." On page ii. of the same volume, a donation is recorded from " Mr. J. Moore. Fragments of bone, teeth, &c., from a Tertiary deposit, exposed by blasting at the Alexandra Battery, One Tree Point." The figured specimens have not yet been located at the Tasmanian Museum, Hobart, but nineteen fragments from the same site numbered Z.164 have been found. Inside they are off-white in colour, with a light-brown (iron oxide) exterior surface. The fragments are ½ to 2 ins. long and ⅛ to 3/16 in. thick. They appear to be mostly fragments of a long bone or bones of a marsupial the size of a kangaroo. Johnston later (1888, pp. 280-281) published a section of the rocks at One Tree Point, and gave some further information about the fossil bones.

2. *Geilston Travertine, Tasmania.*—In the Papers and Proceedings of the Royal Society of Tasmania for 1881 there is a record (p. 12) of " bones obtained by the late Mr. Morton Allport from the Geilston Travertin." Johnston (1880B, 1885E, F) had already reported bones, fruit, leaves, and snails from this formation, which he regarded (1888) as Tertiary in age.

3. *Smeaton, Victoria.*—In an accompanying paper, Professor Stirton (1955B) has described a new genus and species of marsupial as *Glaucodon ballaratensis* (Ballarat being the nearest city) based on a ramus presented to this Museum by J. Marshall in 1914 (reg. No. P.16136). The fossil came from a depth of 50 feet in a well in section 42, Parish of Smeaton, which site is 2½ miles



TEXT-FIGURE 18. Map showing the site of the well from which came *Glaucodon ballaratensis* Stirton. Based on the publications of the Geological Survey of Victoria.

north-west of the village of Smeaton, which is about 16 miles north of Ballarat, Victoria. The writer was conducted to the site by an old resident, J. V. Wilson, and by J. Keenan. As the sides of the well were tending to crumble (a commentary on the nature of the rock), a windmill was set up over the well, and the downpipe was protected with earthenware drain pipes. The space between the earthenware pipes and the sides of the well was then filled in with rock. It was thus not possible to study the walls of the well. However, the general geology of the area is as shown in Quarter Sheet 57 N.-E. and the geological map of the Creswick Gold Field published by the Geological Survey of Victoria. A map based on these is shown in text-fig. 18, on which the site is shown. An intensive study is needed before the fossil can be dated with accuracy, but the materials in which the well was sunk appear to have been laid down subsequently to the eruptions of the volcanoes represented by Mt. Moorookyle and McRorie's Hill. The site is older than Holocene, and is either Pleistocene or Pliocene. The Geological Survey mapped the formation as Upper Pliocene, but in those days (1880) the Pliocene-Pleistocene boundary had not been fixed.

4. *Buninyong, Victoria.*—At the Great Buninyong Eastate Mine at Buninyong, about 6 miles south of Ballarat, marsupial bones were found at a depth of 238 feet in a carbonaceous clay under the basalt. Details of the occurrence have been supplied by Hart (1899), and the bones found referred to *Macropus faunus* by De Vis (1899). Much argument has centered round a piece of a rib of a large marsupial (*?Nototherium*) thought to be a man-made tool (De Vis, 1899; Keble, 1945, 1947). The alleged implement is in the National Museum of Victoria, while the fossil bones are in the Museum of the Ballarat School of Mines. The writer does not consider the piece of rib an implement, and is undertaking fluorine and pollen analyses in an effort to determine the age of the deposit.

5. *Coimadai, Victoria.*—Lacustrine deposits originally considered to be Tertiary in age (Ferguson, 1894; Officer and Hogg, 1897, 1898; Dunn, 1910) were later considered to be definitely Pleistocene by Summers (1923), Coulson (1924), and Keble (1945) on the evidence of marsupial fossils determined by De Vis (in Officer and Hogg, 1898). Coulson also reports some rather indefinite plant remains. Marsupial fossils obtained from the limestone at Coimadai were determined by De Vis as:—

Phascolomys parvus Owen.
Macropus dryas De Vis.
M. anak Owen.
M. cooperi Owen.
Notothere remains.

Macroscopic plant remains in the National Museum from this site consist of *Casuarina* stems and fruits, which give no clear indication of age. A specimen of carbonaceous clay was analysed for pollen but proved negative. However, it is hoped that other investigations under way will be able to date the Coimadai deposit. Dating of this deposit will also date the Rowsley Fault and other important geological features.

There are many other localities with marsupial remains which may be Tertiary in age, and it is suggested that all the older beds containing such remains should be re-studied in the light of recent findings.

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EXPLANATION OF PLATES.

PLATE 1.

Reproduction of Professor Baldwin Spencer's original drawing of *Wynyardia bassiana*. Natural size.

FIG. 1. Dorsal surface of cranium.
FIG. 2. Ventral surface of cranium.
FIG. 3. Axis vertebra from the left side.
FIG. 4. Portion of the pelvic girdle showing the acetabulum and ischium.

PLATE 2.

FIG. 1. Coastal view looking west in the vicinity of Wynyard, north Tasmania. On the left is Fossil Bluff, whence came *Wynyardia*. In the distance is Table Cape which consists of basalt. In the foreground is the shore platform of Permian tillite.

FIG. 2. Fossil Bluff, consisting of Lower Tertiary sediments capped by basalt, and resting on Permian Tillite. The thin darker "*Crassatella* Bed" at the base of the cliff is succeeded by the much thicker "*Turritella* Bed."

FIG. 3. Looking down on the shore platform of Permian tillite, showing drop pebbles in a fine matrix.

PLATE 3.

FIG. 1. Forsyth's Bank on Grange Burn, near Hamilton, Victoria. The cliff consists of Grange Burn Coquina capped by basalt. In the foreground is the underlying Muddy Creek Marl, with remnants of the Nodule Bed on it. The ruins of Forsyth's house can be seen on the top of the cliff, and the motor-truck (top right) provides the scale.

FIG. 2. Bochara Limestone resting on the bedrock of quartz porphyry (left), Grange Burn, west of Henty's house and near the natural arch.

FIG. 3. Natural arch in Bochara Limestone on Grange Burn, west of Henty's house. The limestone is rich in lepidocycline foraminifera and other fossils.

PLATE 4.

FIG. 1. Stump of fossil conifer in fossil soil, covered by vesicular basalt, on south bank of Grange Burn at locality 10 (see text-figure 3), west of Hamilton, Victoria. Scale given by rule, of which a little over 5 ins. is showing.

FIG. 2. Locality 10, Grange Burn, near Hamilton. The fossil *Cuscus* tooth came from the fossil soil under the basalt. The figure in the photo is 5 ft. 4 ins. high.

FIG. 3. Ferruginized sediments of the Grange Burn Coquina in crevices in quartz porphyry country rock at locality 9, Grange Burn (see text-figure 3).

PLATE 1.

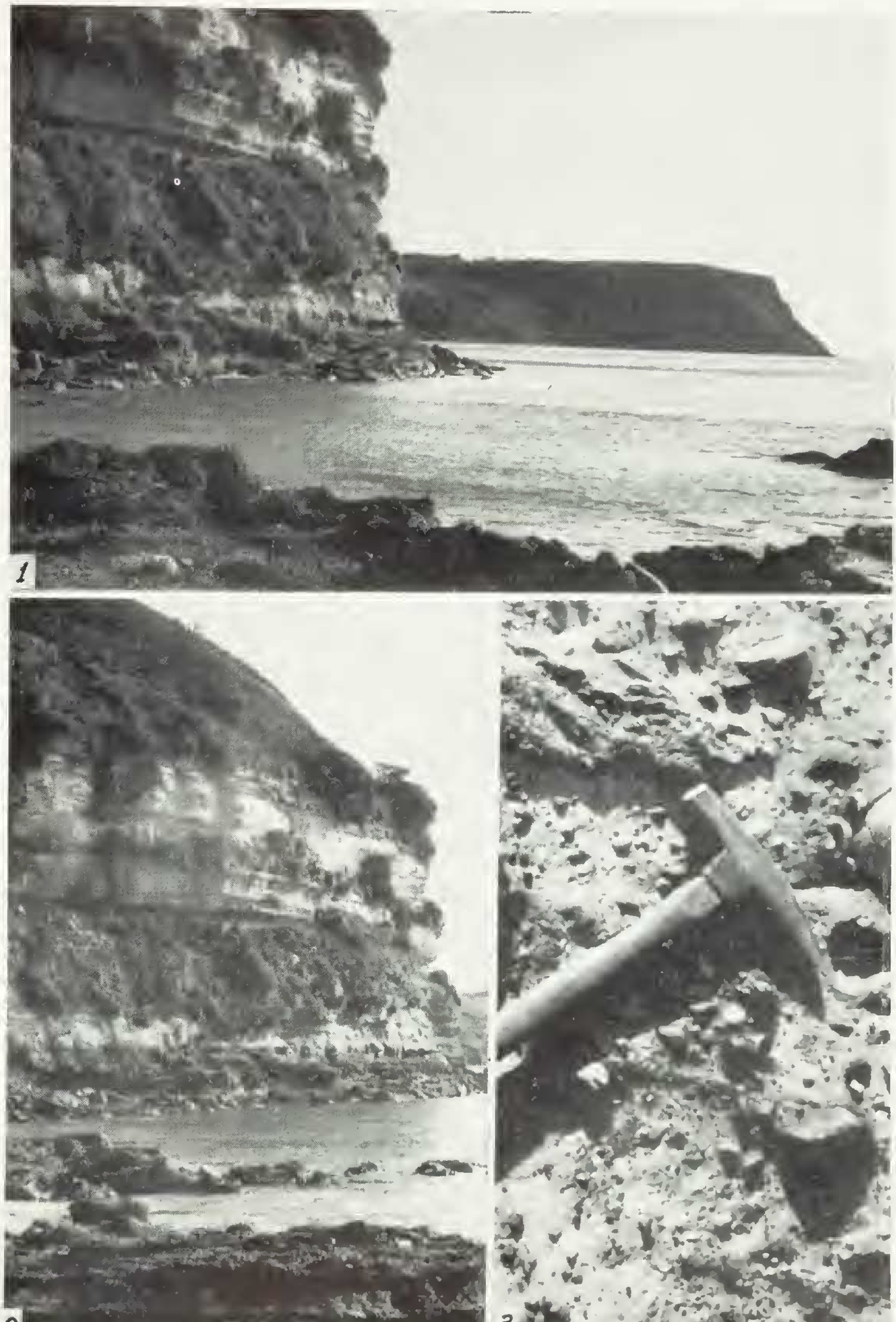

PLATE 2.

PLATE 3.

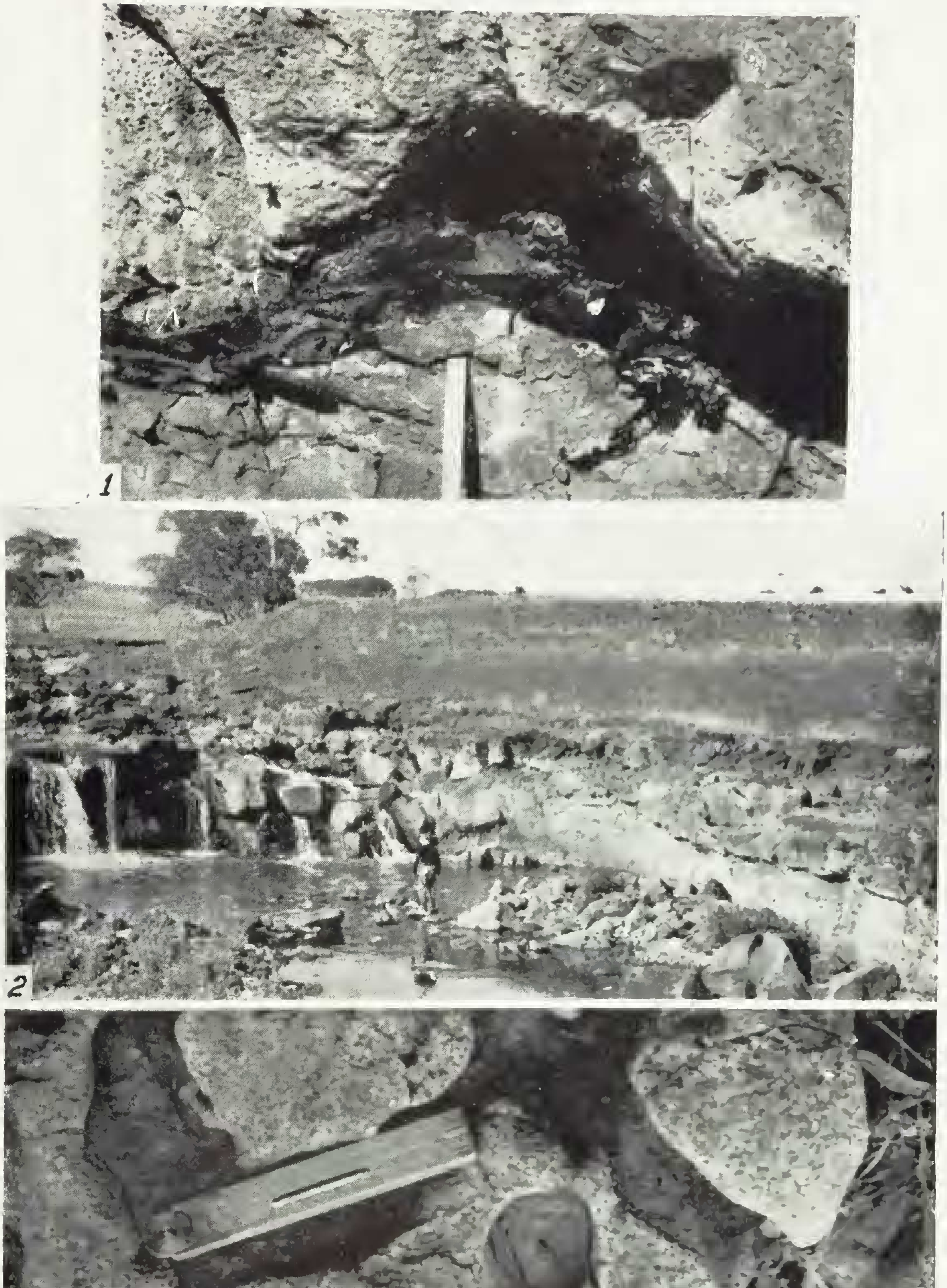

PLATE 4.